U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-297 871

A Technical and Economic Evaluation of the Project in Baltimore, Maryland. Volume II

Systems Technology Corp, Xenia, OH

Prepared for

Environmental Protection Agency, Washington, DC Office of Solid Waste

Jun 79

United States
Environmental Protection
Agency

Office of Water
& Waste Management
Washington, DC 20460

SW 175C.2
June 1979

PB 297871

Solid Waste

A Technical and Economic Evaluation Of the Project In Baltimore, Maryland

Volume II

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

BIBLIOGRAPHIC INFORMATION

PB-297 871

A Technical and Economic Evaluation of the Project in Baltimore, Maryland. Volume II.

Jun 79

PERFORMER: Systems Technology Corp., Xenia, OH.
Contract EPA-68-01-4359

SPONSOR: Environmental Protection Agency, Washington, DC.
Office of Solid Waste.
EPA/530/SW175C.2
Rept. for 1 Oct 75-30 Apr 78.

See also Volume 3, PB-297 872.

One of the first efforts in this country to demonstrate solid waste resource recovery technology was the Baltimore Landgard project which was a joint venture between the City of Baltimore, the U.S. Environmental Protection Agency (EPA), the Maryland Environmental Service, and Monsanto EnviroChem. The Baltimore plant was designed and built by Monsanto EnviroChem to thermally process (pyrolyze) 907 Mg (1000 tons) per day of mixed municipal solid waste, convert it to energy (in the form of steam), and recover magnetic metals and glassy aggregate. Although the plant has never been fully operational in its original design configuration, considerable knowledge has been gained from it concerning resource recovery from municipal solid waste. This report is a complete technical, economic, and environmental evaluation of the Landgard Demonstration Plant at Baltimore, Maryland. It presents an introductory problem analysis of most of the major innovations that proved ineffective, caused serious shutdowns, and required redesign or abandonment.

KEYWORDS: *Solid waste disposal, *Municipal wastes, *Waste processing plants.

Available from the National Technical Information Service, Springfield, Va. 22161

PRICE CODE: PC A15/MF A01

EPA/530/SW-175c.2

A TECHNICAL AND ECONOMIC EVALUATION OF THE PROJECT IN BALTIMORE, MARYLAND

Volume II

This report (SW175c) describes work performed
for the Office of Solid Waste under contract no. 68-01-4359
and is reproduced in four volumes as received from the contractor.
The findings should be attributed to the contractor
and not to the Office of Solid Waste.

U.S. ENVIRONMENTAL PROTECTION AGENCY

1979

i.a

This report was prepared by Systems Technology Corporation, Xenia, Ohio, under Contract No. 68-01-4359.

Publication does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of commercial products constitute endorsement by the U.S. Government.

An environmental protection publication (SW175c) in the solid waste management series.

PREFACE

This report is a complete technical, economic, and environmental evaluation of the Landgard® Demonstration Plant at Baltimore, Maryland. Because of its bulk and to serve a twofold purpose, the report is presented in four volumes: an executive summary, the report proper, an analysis of the problems, and the appendices. Intended particularly for resource recovery planners and administrators, the executive summary briefly and succinctly describes the Landgard® concept and Baltimore application for the state-of-the-art advancement in the processing of municipal mixed solid waste. In addition, it presents an introductory problem analysis of most of the major innovations that proved ineffective, caused serious shutdowns, and required redesign or abandonment. As the second, third, and fouth volumes are detailed in-depth accounts of the evaluation, they were prepared primarily for the designer. Of the four volumes, only the executive summary has been prepared for wide distribution in a paper copy format. The second, third, and fouth volumes are reproduced on microfiche, which is readily available through NTIS.

ABSTRACT

One of the first efforts in this country to demonstrate solid waste resource recovery technology was the Baltimore Landgard® project which was a joint venture between the City of Baltimore, the U.S. Environmental Protection Agency (EPA), the Maryland Environmental Service, and Monsanto EnviroChem. The Baltimore plant was designed and built by Monsanto EnviroChem to thermally process (pyrolyze) 907 Mg (1000 tons) per day of mixed municipal solid waste, convert it to energy (in the form of steam), and recover magnetic metals and glassy aggregate. Although the plant has never been fully operational in its original design configuration, considerable knowledge has been gained from it concerning resource recovery from municipal solid waste. The numerous equipment breakdowns and the inability of the plant to comply with air pollution standards accounted for the major difficulties encountered during the project. Major equipment problems were encountered with the storage and recovery unit, the refractory in the thermal processing vessels, the main induced-draft fan, the residue discharge drag conveyor, and the slag discharge screw conveyor. Despite the fact that the designer recommended converting the plant to a conventional incinerator, plant performance has been sufficiently encouraging to warrant continued investment and operation by the City of Baltimore. One of the primary reasons for this attitude by the City is that the rotary processing kiln has been demonstrated to be an excellent primary reaction vessel. Although the present plant is not environmentally acceptable because of high particulate emissions, this problem will be resolved by the installation of two electrostatic precipitators.

The thermal efficiency of the plant was determined to be approximately 56 percent for an average feed rate of 454 kg per minute (30 tph). The plant has a capital cost of approximately \$22 million, an annual operating and maintenance cost of \$3 million, and an annual steam revenue of \$1 million. The net operating cost, based on historical operating data, is \$64.10 per Mg (\$58.20 per ton) of refuse processed. However, if the annual throughput of 67,000 Mg (74,000 tons) could be substantially increased to 270,000 Mg (300,000 tons), operating cost could be reduced to \$7.80 per Mg (\$7.10 per ton) of refuse processed.

This report is submitted in fulfillment of Contract No. 68-01-4359 by Systems Technology Corporation (SYSTECH) under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from October 1, 1975 to April 30, 1978.

CONTENTS

Preface i

Abstract ii

Figures v

Tables x

List of Unit Conversions xvi

Acknowledgment xvii

1. Background 1

2. Plant Description and Analytical Operation Review 6

    Receiving module 7

    Size reduction module 19

    Storage and recovery module 49

    Thermal processing module 81

    Energy recovery module 172

    Residue separation module 206

    General plant 227

3. Mass and Energy Balance 239

    Waste preparation subsystem 240

    Thermal processing subsystem 245

4. Environmental Assessment 264

    Stack emissions 264

    Solid residues 267

CONTENTS (continued)

Plant process waters 275

Fugitive emissions 277

Noise 279

5. Economic Evaluation 288

Background and purpose 288

Operating and maintenance costs 292

Capital costs 295

Revenues 305

Net operating costs 306

6. Administrative Assessment 307

Parties involved 307

Organization of groups involved 308

Overall effects of organization 313

Conclusions 313

7. Future plant 315

Ongoing and proposed modifications 315

Second generation facility 320

FIGURES

Number		Page
1	Process flow diagram of the Baltimore Landgard facility	8
2	The receiving module	9
3	An example of the weight tickets used at the pyrolysis plant	11
4	Refuse truck routing plan	13
5	Schematic of the receiving building	15
6	Refuse truck discharging to the direct dump chute	16
7	Empty storage pit	17
8	Full storage pit	18
9	Size reduction module	20
10	Storage pit bulldozers	21
11	An exploded view of the apron conveyor	23
12	A typical section through a storage pit conveyor	24
13	A typical section through a shredder feed conveyor	26
14	Control panel in main control room	27
15	Link failure on shredder feed conveyor	28
16	Schematic of a hammermill shredder	33
17	Rebuilt shredder hammers	34
18	Worn shredder hammers	34
19	Fenwall sensor and extinguisher	38

FIGURES (continued)

20 A recording ammeter graph of shredder current 41

21 Probability plot of shredder current 42

22 Shredder discharge conveyor 47

23 Storage and recovery module 50

24 Transfer tower 52

25 Refuse jam at the elevating conveyor discharge 54

26 Magnetic drum separator system and bypass chutes 57

27 Stored material spreader 62

28 Schematic of the storage and recovery unit 65

29 Buckets used in the storage and recovery unit 66

30 Bridging of refuse against silo walls 69

31 Loosening of the waste in the storage and recovery unit 70

32 Buckets undercutting the refuse pile in the silo 70

33 Ten bucket chains contacting the refuse pile in the silo 72

34 Twenty bucket chains contacting the refuse pile in the storage and recovery unit 72

35 Uniform width bucket wear show (type B) 73

36 Differential width bucket wear shoe (type C) 74

37 Elongated bucket wear shoe (type D) 75

38 Regular bucket wear shoe (type E) 76

39 Floor wear measurement points 78

40 Thermal processing module 83

41 Schematic of the ram feeders 87

FIGURES (continued)

42 Deformed ram snouts 90

43 Schematic of the kiln 93

44 The kiln 94

45 Kiln discharge during standby operation 94

46 Kiln Flights 95

47 Kiln auxiliary equipment 97

48 Kiln Tunnions 98

49 Kiln processing zones 100

50 Kiln residue slag balls 102

51 Vortex gas flow in the kiln 104

52 Conical expansion of kiln ends and corrective slots 106

53 Gas purifier 112

54 Schematic of the gas purifier 113

55 Fallen orifice baffle wall in the gas purifier 116

56 Deteriorated refractory and etched mortar in the gas purifier 117

57 Fallen orifice baffle wall in the gas purifier 118

58 Slag taphole dam with V-notch weirs 119

59 Plugged slag taphole 120

60 Propane burners in the slag taphole 129

61 Original residue quench tank and conveyor 134

62 Modified residue quench tank and conveyor 137

63 Schematic of the seal tank 140

64 Butterfly valve quench air damper 145

FIGURES (continued)

65 Gas scrubber 147
66 Process flow diagram of the gas scrubber 149
67 Induced-draft fam rotor 165
68 Induced-draft fan rotor vane 165
69 Dehumidifier 166
70 Dehumidifier inlet vestibule 169
71 Dehumidifier outlet vestibule 169
72 Area fumigation by exhaust gases 171
73 Dehumidifier condensate pipe corrosion 171
74 Energy recovery module 173
75 Schematic of the waste heat boilers 188
76 Fly ash accumulating on the first row of boiler tubes 190
77 Schematic of the jug valve 196
78 Jug valve 197
79 Fly ash build-up in the boiler inlet duct 199
80 Blowdown surge tank and separator 202
81 Residue separation module 207
82 Magnetic metal separation conveyor 224
83 Waste preparation subsystem sampling points 241
84 Waste preparation subsystem mass and energy balance 246
85 Thermal processing subsystem sampling points 247
86 Kiln mass and energy balance 254
87 Gas purifier mass and energy balance 257

FIGURES (continued)

88 Boiler mass and energy balance 261

89 Thermal processing subsystem mass and energy balance 262

90 Total plant mass and energy balance 263

91 Noise survey 281

92 Noise survey 282

93 Noise survey 283

94 Noise survey 284

95 Noise survey 285

96 Noise survey 286

97 City administration structure pertaining to pyrolysis plant 310

98 Original procurement procedure for the City of Baltimore 312

99 Proposed future plant look 316

TABLES

Number Page

1 Chronology of Landgard Development 1

2 Design variations in St. Louis Landgard prototype and full-scale Baltimore facility 2

3 Chronology of Landgard Demonstration at Baltimore 3

4 Receiving area time study 12

5 Apron conveyor preventive maintenance schedule 31

6 Shredder hammer wear 36

7 Shredder power consumption 37

8 Shredding rate 40

9 Shredder preventive maintenance schedule 44

10 Vibrating pan conveyor preventive maintenance schedule 49

11 Shredded refuse conveyor preventive maintenance schedule 56

12 Magnetic drum separator preventive maintenance schedule 60

13 Stored material spreader preventive maintenance schedule 63

14 Life of bucket wear shoes 77

15 Floor wear data 79

16 Storage and recovery unit preventive maintenance schedule 82

17 Ram feeder preventive maintenance schedule 91

TABLES (continued)

Number		Page
18	Kiln refractory	95
19	Kiln preventive maintenance schedule	110
20	Kiln feed hood preventive maintenance schedule	111
21	Gas purifier preventive maintenance schedule	121
22	Preventive maintenance schedule	126
23	Preventive maintenance schedule	127
24	Fuel oil burner system preventive maintenance schedule	132
25	Fuel oil pumps preventive maintenance schedule	133
26	Quench tank preventive maintenance schedule	138
27	Quench tank conveyor preventive maintenance schedule	138
28	Seal tank preventive maintenance schedule	144
29	Screw conveyor preventive maintenance schedule	144
30	Gas scrubber preventive maintenance schedule	150
31	Scrubber water pump preventive maintenance schedule	153
32	Caustic unloading pump preventive maintenance schedule	155
33	Sludge pump preventive maintenance schedule	158
34	Clarifier preventive maintenance schedule	160
35	Floc feed system preventive maintenance schedule	161
36	Sump pump preventive maintenance schedule	162

TABLES (continued)

Number Page

37 Induced draft fan preventive maintenance schedule 167

38 Dehumidifier fan preventive maintenance schedule 172

39 Brine pump preventive maintenance schedule 176

40 Degasifier pump preventive maintenance schedule 180

41 Deaerating heater preventive maintenance schedule 182

42 Agitator preventive maintenance schedule 184

43 Feedwater pump preventive maintenance schedule 186

44 Micrometer measurements of boiler tubes 191

45 Boiler tube corrosion 191

46 Boiler preventive maintenance schedule 194

47 Jug valve preventive maintenance schedule 200

48 Fly ash transfer system preventive maintenance schedule 205

49 Vibrating screen conveyors 208

50 Residue flotation unit 211

51 Separation air compressor 212

52 Roto screen preventive maintenance schedule 213

53 Thickener preventive maintenance schedule 216

54 Pressure pump preventive maintenance schedule 217

55 Underflow pump preventive maintenance schedule 218

TABLES. (continued)

Number Page

56 Vacuum belt filter preventive maintenance schedule 220

57 Vacuum pump preventive maintenance schedule 221

58 Filtrate pump preventive maintenance schedule 222

59 Rubber belt residue conveyor preventive maintenance schedule 223

60 Magnetic metal separator preventive maintenance schedule 226

61 Atomizing steam boiler preventive maintenance schedule 229

62 Instrument air compressor preventive maintenance schedule 233

63 Instrument air drier preventive maintenance schedule 234

64 Dust collector preventive maintenance schedule 236

65 Wastewater lift station pump preventive maintenance schedule 238

66 A comparison of refuse composition 243

67 Refuse composition 244

68 Residue composition 251

69 Kiln off-gas composition 252

70 Average ash chemistry of gas purifier slag 255

71 Composition of gas purifier exit gases 256

72 Dry electrostatic precipitator test of boiler exit gases 265

73 Boiler and scrubber outlet gases 266

TABLES (continued)

Number		Page
74	Hydrocarbon analysis of boiler and scrubber outlet gases	266
75	Emission spectrographic scan of slag	269
76	Slag leachate analysis	270
77	A comparison of kiln and incinerator residues	271
78	Residue putrescible content	271
79	Microbial analysis of residue	272
80	Residue leachate analysis	273
81	Boiler fly ash chemistry	274
82	Boiler fly ash analysis of aqua regina solubles	275
83	Average analysis of various process waters	276
84	Dust levels	278
85	Microbial levels in refuse dust	278
86	Analysis of receiving building air	280
87	Noise levels during soot blowing	287
88	Scenario operating parameters	290
89	Operating and maintenance unit cost data	293
90	Projected annual operating and maintenance costs	295
91	Operating and maintenance cost per cost center	296
92	A summary of EPA capital cost classifications	298
93	Capital costs (exclusions/additions)	300

TABLES (continued)

Number Page

94 Equipment costs and useful life reported by selected vendors 301

95 Projected scenario capital cost summary 302

96 Summary cost center distributions 303

97 Capital costs per EPA cost center including adjustments 304

98 Subsystem capital costs 305

99 Project cost summary 306

LIST OF UNIT CONVERSIONS

Description	SI		English Equivalents	
	Unit	Symbol	Unit	Symbol
Length	meter	(m)	3.28 feet	(ft)
	centimeter	(cm)	0.394 inches	(in.)
	millimeter	(mm)	39.37 mils	-
	micrometer	(mm)	1.0 micron	-
Area	square meter	(m^2)	10.76 square feet	(ft^2)
Volume	cubic meter	(m^3)	35.31 cubic feet	(ft^3)
	liter	(l)	0.264 gallons	(gal)
Mass	kilogram	(kg)	2.20 pounds	(lbs)
	megagrams	(Mg)	1.10 tons	(t)
Pressure	kilopascal	(kPa)	0.145	(lbs/in.^{2})
Temperature	celsius	(C)	5 fahrenheit/9-17.8	(F)
Energy	joule	(J)	9.48×10^{-4}	(Btu)
Density		(kg/m^3)	.0624	(lbs/ft^3)
Energy/Mass		(MJ/kg)	431	(Btu/lb)
Mass Loading		(g/DSCM)	0.437	(gr/DSCF)
Concentration		(µl/l)	1.0	(ppm)
Power	kilowatt	(kw)	0.06	(MJ/min)

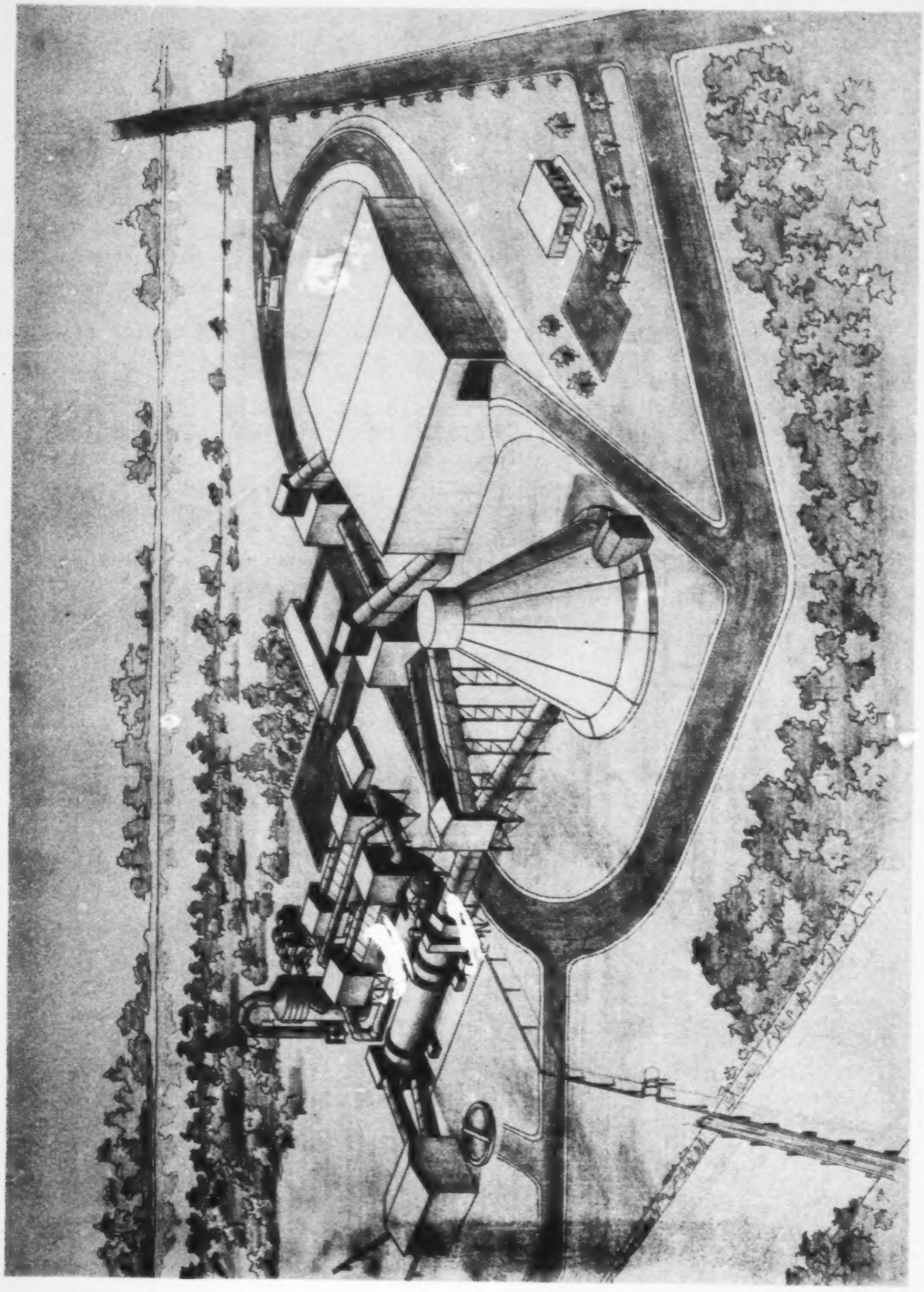
ACKNOWLEDGMENT

This evaluation program was performed under EPA Contract No. 68-01-4359, "Technical and Economic Evaluation of the EPA Demonstration Resource Recovery Project in Baltimore, Maryland."

The EPA Project Officer was Mr. David B. Sussman of the Office of Solid Waste, Washington, D.C.

Testing was carried out at the demonstration facility in Baltimore, Maryland with the cooperation of the City plant staff and the Monsanto on-site engineering staff. The contribution of both of these groups has been greatly appreciated. The contribution of Dr. H. G. Rigo and Richard Eckels, along with other staff members, is also acknowledged.

Systems Technology Corporation would like to express its gratitude to the above named individuals and all others associated with this evaluation.



BALTIMORE LANDGARD® FACILITY

SECTION 1

BACKGROUND

Monsanto became involved in solid waste processing in 1967 when they commissioned an internal study to determine the best methods of solid waste disposal. By August 1968 they had determined that direct pyrolysis was an attractive method of solid waste disposal warranting further investigation. Monsanto's Landgard® process was subsequently developed, and an evaluation was begun. Early in 1969 a benchscale unit was designed and operated in Dayton, Ohio, for concept confirmation. The results were sufficiently encouraging that by June 1969 a 32-MgPD (35-TPD) prototype kiln was operating in St. Louis, Missouri. Another 32-MgPD (35-TPD) unit was placed in operation in Kobe City, Japan, by Kawasaki Industries, a licensee of the Landgard® process. The Baltimore project was begun in late 1972 and officially initiated in January 1973. Table 1 is a review of the developmental period of the Landgard® technology.

TABLE 1. CHRONOLOGY OF LANDGARD® DEVELOPMENT

Date	Stage Of Development
Fall 1968	Bench-scale prototype, Dayton, Ohio; 0.27 to 0.54 MgPD capacity, 0.3- × 1.5-m kiln
Spring 1969	Small-scale prototype, St. Louis, Missouri; 32 MgPD, 1.2- × 6.1-m kiln
Spring 1974	Small-scale prototype, Kobe City, Japan; 32 MgPD, 1.2- × 6.1-m kiln
Nov. 1974	Full-scale prototype, Baltimore, Maryland; 907 MgPD, 6.1- × 30.5-m kiln

Most of the design data for the Baltimore facility were projected from the experience gained at the prototype unit located in St. Louis, Missouri. This unit was operated from fall 1969 until late 1971 but was never continuously operated for more than 1 week.

A number of differences existed between equipment items and operational procedures at the St. Louis prototype and the Baltimore facility (Table 2). These variations limited the applicability of the St. Louis experience and became even more critical when the scale-up factor of 32 was considered.

TABLE 2. DESIGN VARIATIONS IN ST. LOUIS LANDGARD® PROTOTYPE AND FULL-SCALE BALTIMORE FACILITY

Prototype facility (32 MgPD)	Full-scale facility (907 MgPD)
Concrete slab receiving area (tipping floor)	Dozer pit
Use of rubber belt conveyors in receiving area	Use of steel apron conveyors in receiving area
Use of vertical shaft shredders for size reduction	Use of horizontal shaft hammermills for size reduction
Non-slagging gas purifier	Slagging gas purifier
No heat recovery system	Two waste heat boilers and economizers
Stack	Dehumidifier
Secrew-type residue discharge conveyor	Drag-type residue discharge conveyor
Materials separation in residue quench tank	Separate materials separation equipment components
No slag/spillback removal system	Secrew conveyor slag/spillback removal system
No magnetic separation before pyrolysis	Magnetic drum separator before pyrolysis
Thickener for char dewatering	Thickener and vacuum belt filter for char dewatering
Two propane burners in kiln, no burners in gas purifier	Two main burners and four safety burners in kiln, three burners in gas purifier (all using #2 fuel oil), plus two propane burners in gas purifier
Entrance of shredded refuse into storage and recovery unit before entrance into kiln	Ability to direct shredded refuse to storage and recovery unit or directly to kiln

In 1972 the City of Baltimore and Monsanto EnviroChem entered into an agreement to design and construct a 907-MgPD (1,000-TPD) resource recovery facility to be installed in the City of Baltimore, where it would be owned and operated by the municipal government. In conjunction with this agreement, a grant from the U.S. Environmental Protection Agency (EPA) and a grant/loan from Maryland Environmental Services were obtained for supplemental funding of the Baltimore facility in the amount of $10 million. Table 3 outlines the major events that occurred in conjunction with the demonstration.

TABLE 3. CHRONOLOGY OF LANDGARD® DEMONSTRATION AT BALTIMORE

DATE	STAGE OF DEVELOPMENT
July 14, 1972	Monsanto proposal submitted
Sept. 8, 1972	Monsanto proposal grant awarded
Oct. 11, 1972	Original contract submitted
Jan. 10, 1973	Amended contract approved Construction design begun
Nov. 4, 1974	Plant debugging begun
Jan. 31, 1975	Construction completed, plant commissioned
Nov. 1, 1975	Supplemental agreement made for Phase I and II modification projects
Jan. 1, 1976	Phase I modification work begun
April 23, 1976	Phase I modifications completed
May 6, 1976	Phase I operations begun
Aug. 9, 1976	Phase II modifications begun
Nov. 5, 1976	Phase II modifications completed
Nov. 6, 1976	Phase II operations begun
Jan. 31, 1977	Project termination recommended by Monsanto
Feb. 18, 1977	Monsanto personnel leave site; decision made by City to continue testing

Under the agreement, the City of Baltimore was responsible for obtaining an acceptable site, bearing site preparation costs, and supplying the operating and maintenance personnel and budget for the plant at the outset of the demonstration. Agreements were made for the sale of the recovered byproducts: steam, glassy aggregate, and magnetic metal. The duration of these agreements was for the period of the demonstration (1 year).

Under the terms of the agreement, Monsanto EnviroChem was responsible for providing manpower during the grant demonstration on a contracted level of 70 man-days per month. The responsibility of this staff was to train and supervise the City's operating and maintenance personnel before and during the demonstration period.

The design, procurement, and construction effort was contracted to be completed within 18 months of contract award. Although the general process design was already complete at the time of contract award, the specific design details of the Baltimore facility were not. As a result, the 18-month schedule was exceptionally short for the total effort required.

Construction of the facility was supervised by Leonard Construction, a wholly-owned subsidiary of Monsanto EnviroChem. Leonard Construction had historically been responsible for the construction of sulfuric acid plants designed by Monsanto EnviroChem. Members of the construction group remained on site to supervise the implementation of equipment modifications made during the start-up phase of the project. As shown in Table 3, construction required 24 months to be completed, rather than the 18 specified in the contract. However, portions of the facility were released in a staged fashion starting in late October 1974. A phased start-up effort was thus allowed, beginning with the receiving area and continuing through the process line as each process area was released by construction. The presence of construction personnel in the area of operating equipment created some minor operational problems.

From January 21 through November 1, 1975, the facility operated for short periods, but no sustained operation was achieved. During this period, extensive operational testing was performed to determine the optimum operating characteristics of the facility. Numerous mechanical and operational problems were encountered, and modifications were made on the equipment items in an attempt to alleviate some of these problems. Major problems encountered at this stage of the demonstration were: (1) difficulty with storage and recovery unit material retrieval, (2) kiln refractory failure, (3) excessively high kiln temperatures and an unstable kiln process, (4) residue drag conveyor failure, (5) ram feeder jamming, (6) gas purifier slag tap-hole plugging, (7) high induced draft fan vibration, and (8) high stack gas particulate emission levels. Variations in the mode of operation were executed in an effort to alleviate these problems, but only minor success was achieved.

By late 1975, Monsanto EnviroChem acknowledged the failure of the plant to meet the emissions and reliability guarantees. At that time, Monsanto agreed to forfeit their $4 million liability to the City of Baltimore and renegotiated a new contract with the City. (The second contract is referred to as the Supplemental Agreement.) At this time, EPA supplied an additional $1 million to provide the total requirement of $5 million that Monsanto believed would bring the plant to an acceptable level of operation. The plant was inoperative from late 1975 to May 1976 to allow modifications hoped to improve the mechanical reliability of plant equipment.

Subsequent to this first phase of modification, the plant operated at a higher percentage of on-stream time than at earlier stages of the demonstration, but satisfactory levels had not yet been reached. Operational testing was continued through the period to further define the modifications required to improve plant reliability. As a result of the longer periods of continuous operation accompanying the improvements, three weeks versus one week, a new group of problems became apparent--erosion of the refractory in the gas purifier, wear in the storage and recovery unit, corrosion/erosion of the induced draft fan impeller and scrubber auxiliaries, and inability to operate the materials recovery area on a continuous basis. Although the problems experienced earlier in the demonstration occurred less frequently during this period, none of them were completely resolved.

The facility was shut down again for 3 months late in 1976 to complete a second phase of modifications. During this period, major changes were made in the process equipment in a continuing effort to increase reliability. The results of these modifications were significant, and a definite increase in on-stream time occurred. The replacement of the kiln refractory, utilizing a rotary pour technique and stainless steel fiber reinforced coarse refractory, has solved the failure problem of the kiln refractory. No major failures have occurred in this area since the replacement was made. The addition of a circumferential air inlet duct at the residue discharge end of the kiln helped to reduce the refractory problem and improve process control stability. Oil- and propane-fired burners placed in the slag taphole in the gas purifier to minimize plugging had a positive effect, but the problem still recurred after the modification. Attempts to prevent refractory failure in the gas purifier failed, as did those aimed at reducing corrosion in the scrubber system. The decision was made during this period to abandon attempts at operating the residue separation area, pending acceptable functioning of the thermal processing area. It was also decided that a dry electrostatic precipitator would be required to reduce plant stack emissions to an acceptable level.

Despite the fact that the plant operated at the highest level of throughput experienced during the demonstration (64,760 MgPY or 71,400 TPY), Monsanto EnviroChem recommended that the project be terminated and left the facility in February 1977.

The City of Baltimore has continued to modify the plant without the assistance of Monsanto EnviroChem and intends to change the basic design to achieve higher plant reliability. The City no longer operates the storage and recovery unit or the wet gas scrubber; rather, both units are simply bypassed because they are unable to perform adequately. Despite the efforts made to date, the process still does not operate on a continuous basis. The major remaining problems are the refractory failure in the gas purifier, slag taphole plugging, slag removal screw conveyor jamming, and failure of the plant to meet emissions standards. The design phases have been completed, and construction has been initiated on modifications to change the gas purifier from a slagging to a nonslagging operation. An electrostatic precipitator is being installed to replace the wet gas scrubber and to control the level of particulate emissions, and a stack is being erected in place of a ground-level dehumidifier unit.

The City of Baltimore has received additional Federal funding through the Economic Development Administration that will be used to implement the modifications outlined above. The City intends to continue to utilize the process (for their solid waste) as part of their overall waste disposal plan.

SECTION 2

PLANT DESCRIPTION AND ANALYTICAL OPERATION REVIEW

The Landgard® Demonstration Plant at Baltimore, Maryland, was designed to handle mixed municipal solid waste with the two-fold objective of reducing the mass and volume of the waste to a minimal residue for the most economical landfill disposal and of recovering the energy and reusable materials in the waste.

This section describes the plant subsystems and components, their operational interrelationships and performance, and their required maintenance and modifications. In addition, this section details and analyzes the subsystem/component functioning, compares the subsystem/component design and actual performance, and offers suggestions or recommendations for plant equipment and operational procedure modification.

To simplify the comprehensive analysis and description of the Landgard process implementation at the Baltimore facility, the plant has been divided into seven subsystems or modules. In this report, the term "module" denotes the functionally integrated plant components which make up a subsystem that performs, in general, a specific primary operation or serves a supporting role in the performance of one or more operations in the overall plant process.

Accordingly, the nomenclature for each module was selected to represent the primary operation of the functionally integrated components constituting the given module as designed. The seven modules, therefore, are (1) Receiving, (2) Size reduction, (3) Storage and recovery, (4) Thermal processing, (5) Energy recovery, (6) Residue separation, and (7) General plant.

Since some of the plant subsystems and components were discontinued at different stages of the demonstration period and for various reasons, the following summary of the modules describes their status during the initial plant operation.

The receiving module weighs the refuse in the city packer trucks and then stores the dumped waste until it can be fed to the size reduction module. In the second module, the refuse is shredded and discharged to the storage and recovery module which discharges the refuse at a controlled rate to the thermal processing module or to chutes which bypass the storage and recovery unit for direct discharge to the thermal processing module. In this fourth module, most of the shredded refuse is gasified and combusted; then the gaseous products are discharged to the energy recovery module, the fifth module, and the solid residue is transported to the residue separation module, the sixth module. While the energy in the gaseous products is recovered in the energy recovery module by producing steam from the sensible heat, the solid residue is separated in the residue separation module into streams of various types of reusable materials and waste. Finally, the seventh and last module, the general plant module, provides processes and systems that are common to two or more of the other modules.

Figure 1 presents a simplified flow diagram of the Baltimore Landgard plant. In the following sections detailing each of the seven modules, the given module is indicated by the shaded areas in the adaptation of this figure.

Most of the plant unreliability, that is, occasions when the entire plant had to be shut down, were due to operational or equipment failures in the storage and recovery and the thermal processing modules, as discussed later. After a short operational period, the residue separation module was discontinued because of marginal economics and the extensive manpower requirements.

RECEIVING MODULE

As represented by the shaded areas in Figure 2, the receiving module was designed to accept the mixed municipal solid waste delivered by city packer trucks as they entered the plant with minimal waiting time. The shaded areas in this figure indicate the principal section of this module, namely, the weighing scale, the tipping floor, and the storage pit.

To provide for a continuous stream of trucks, ten truck dumping bays are available on the tipping floor and the storage pit has ample capacity for the surge waste deposits. The waste accumulation is normally sufficiently deep to permit preparing a constant-volume flow of refuse onto conveyors for transfer to the size reduction module.

The receiving module has had few operational problems because of the simplicity of the equipment and procedure.

Refuse Truck Weighing System

The refuse in each truck entering the Baltimore pyrolysis plant is measured by simply subtracting the tare weight from the load weight registered in the plant's weighing system.

The truck weighing system consists of a Toledo Model 820-8130 load cell type, 45-Mg (50-ton) motor truck scale with a 3.0-m (10-ft) by 15.2 m (50-ft) platform and a steel-framed structure with glass on all four sides which houses an operator's scale-control panel. The scale is equipped with a digital indicator, card reader, math module, and source record punch. The arrangement with the large-scale platform rather than that for measuring the axle weight of vehicles was selected because of its operational speed and simplicity. To ensure that no truck weight would exceed the scale limit, the 45-Mg (50-ton) capacity was chosen since this weight is greater than the legal load for Maryland trucks.

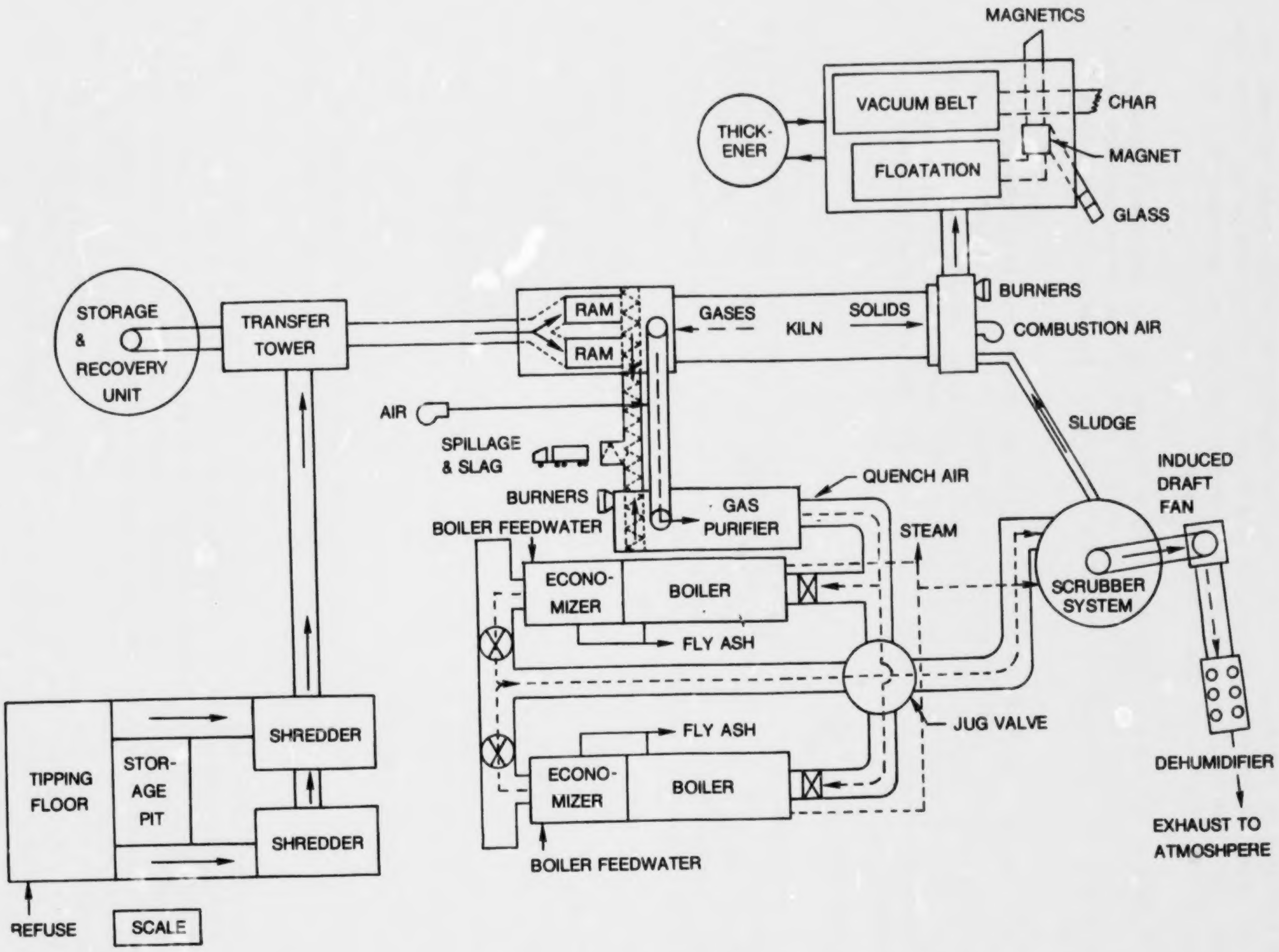

MAGNETICS
VACUUM BELT
CHAR
THICK-ENER
MAGNET
FLOATATION
GLASS
BURNERS
COMBUSTION AIR
STORAGE & RECOVERY UNIT
TRANSFER TOWER
RAM
RAM
GASES
KILN
SOLIDS
AIR
SLUDGE
SPILLAGE & SLAG
QUENCH AIR
INDUCED DRAFT FAN
BURNERS
GAS PURIFIER
BOILER FEEDWATER
STEAM
ECONO-MIZER
BOILER
SCRUBBER SYSTEM
FLY ASH
JUG VALVE
FLY ASH
SHREDDER
TIPPING FLOOR
STOR-AGE PIT
ECONO-MIZER
BOILER
DEHUMIDIFIER
SHREDDER
BOILER FEEDWATER
EXHAUST TO ATMOSHPERE
REFUSE
SCALE

Figure 1. Process flow diagram of the Baltimore Landgard® facility.

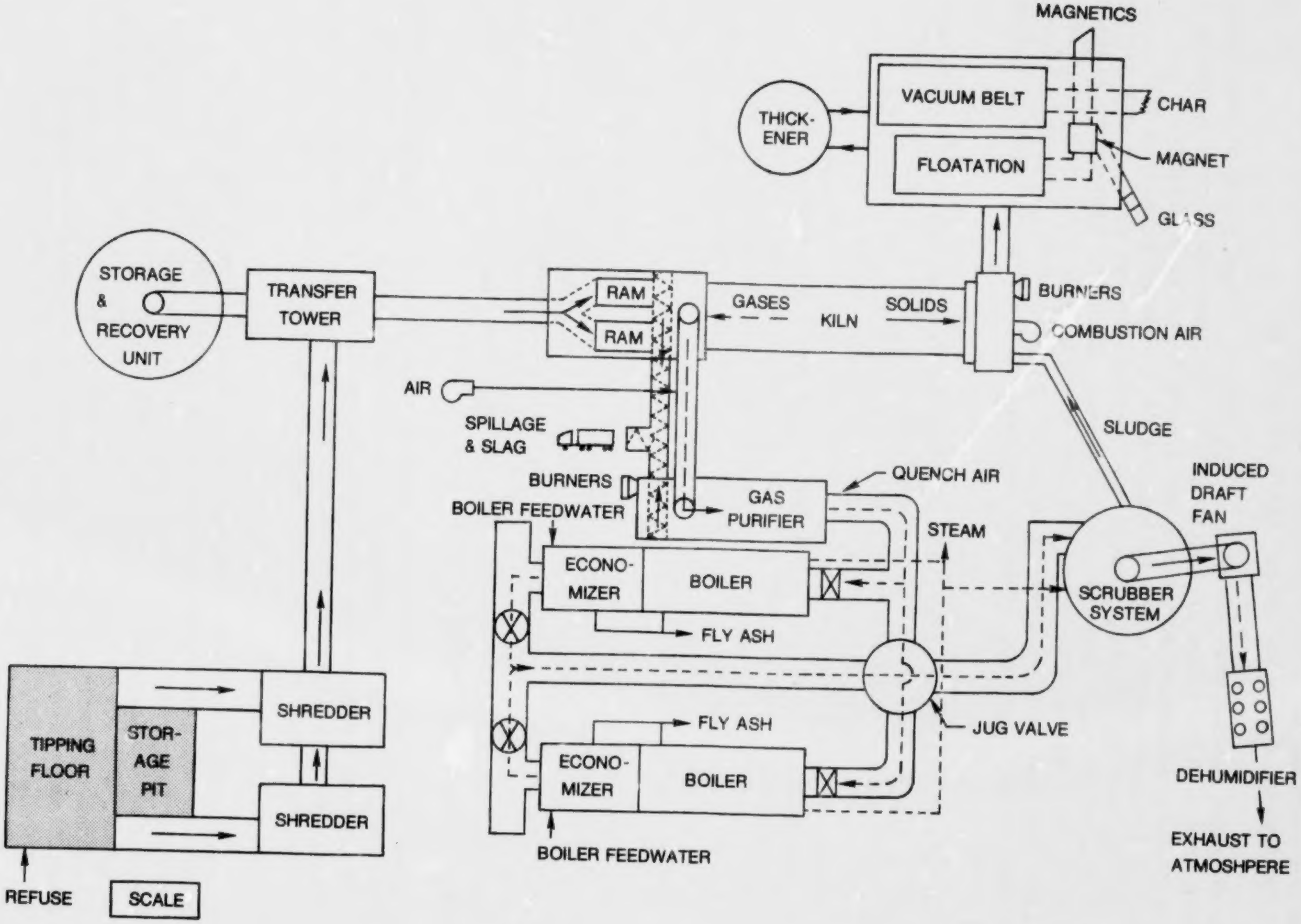

MAGNETICS
VACUUM BELT
CHAR
THICK-ENER
FLOATATION
MAGNET
GLASS
STORAGE & RECOVERY UNIT
TRANSFER TOWER
RAM
RAM
GASES
KILN
SOLIDS
BURNERS
COMBUSTION AIR
AIR
SPILLAGE & SLAG
SLUDGE
BURNERS
QUENCH AIR
GAS PURIFIER
INDUCED DRAFT FAN
BOILER FEEDWATER
STEAM
ECONO-MIZER
BOILER
SCRUBBER SYSTEM
FLY ASH
TIPPING FLOOR
STOR-AGE PIT
SHREDDER
SHREDDER
FLY ASH
JUG VALVE
ECONO-MIZER
BOILER
DEHUMIDIFIER
BOILER FEEDWATER
EXHAUST TO ATMOSHPERE
REFUSE
SCALE

Figure 2. The receiving module (shaded area).

In a modification to the original receiving schedule of 6 days per week (Monday through Saturday), 7 a.m. to 4 p.m., the Saturday operation was reduced to 5 hours, 7 a.m. to 12 p.m., so that only one scale clerk working with limited overtime would be required thereby conforming to the hiring constraints imposed during the plant start-up period.

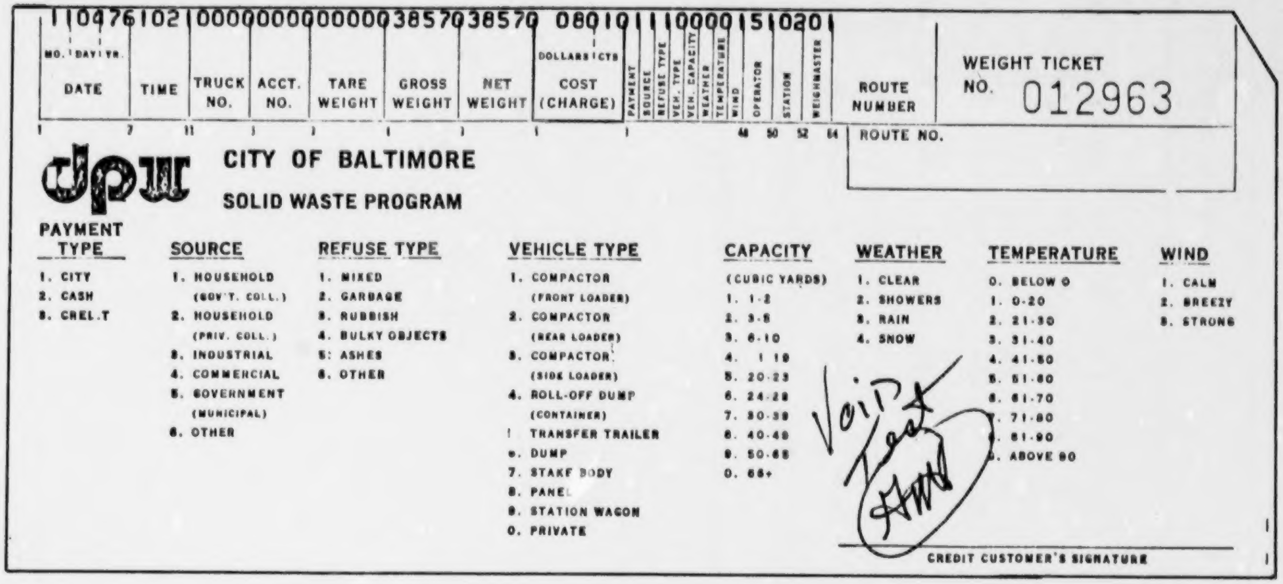
The weighing system was designed to accommodate three types of vehicles: (1) packer trucks which would normally collect and dump the city's curbside refuse on regular schedules and which would have known tare weights, (2) transfer trailers which would be handled in a similar manner as the packer trucks, and (3) privately owned and operated trucks which would not be scheduled and which would require tare weighing. However, because of limitations during the plant start-up and initial operation, only the city packer trucks have thus far been allowed to enter the plant. When plant operations approach the design capacity, transfer trailers will likely be used to reduce hauling costs.

To eliminate operator error in recording the load weight of each truck, the weighing system design included the following: First, a plastic card with the truck number and tare weight was prepared for each city packer truck. Then, as a truck enters the plant, the scale operator would insert the truck's card in the control panel. Next, as the gross weight of the truck was measured on the scale, the net weight would be automatically calculated and printed along with all the pertinent information on the punch card weight ticket for subsequent processing by the City computers (see Figure 3). However, because of the excessive delays in the computer processing, the cards have not been used as intended, and the operator has been recording the information manually.

In addition to the punch cards currently not being used as intended, their retrieval as trucks enter the plant frequently causes truck backups because of the excessive time that the scale clerk needs in trying to find the appropriate cards. A tentative remedy to this situation could be painting the tare weight on the side of each truck and having the scale clerk manually enter both the truck number and the tare weight into the scale system. The results of a receiving area time study are shown in Table 4.

As shown in Figure 4, the truck-routing plan through the plant requires that trucks pass through the processing area before being weighed to prevent truck back up from interferring with traffic on the public thoroughfare. This routing not only disrupts the normal flow of people and service vehicles in the processing area but also poses a safety hazard to personnel and equipment.

The scale operator communicates with the truck drivers through an intercom system and gives them their weigh-in tickets through an air-lock Deibolt drawer installed in the scale house to maintain a comfortable temperature for the operator. However, the indirect voice transmission coupled with the drawer operation has further delayed the operator-driver transaction and contributes to the truck back ups. In view of this delay and the scale house temperature control difficulty discussed in the next paragraph, a sliding window or a door on the scale side of the house would provide a



1 1 04 76 102 1 0000 0000 0000 03857 03857 0 080 10 1 1 1 0000 1 5 1 02 0 1

MO. DAY YR. DATE	TIME	TRUCK NO.	ACCT. NO.	TARE WEIGHT	GROSS WEIGHT	NET WEIGHT	DOLLARS CTS COST (CHARGE)	PAYMENT SOURCE REFUSE TYPE VEH. TYPE VEH. CAPACITY WEATHER TEMPERATURE WIND	OPERATOR	STATION	WEIGHMASTER
1	7	11							48	50	52 54

ROUTE NUMBER

WEIGHT TICKET NO. 012963

ROUTE NO.

CITY OF BALTIMORE

SOLID WASTE PROGRAM

PAYMENT TYPE
1. CITY
2. CASH
3. CREI.T

SOURCE
1. HOUSEHOLD (GOV'T. COLL.)
2. HOUSEHOLD (PRIV. COLL.)
3. INDUSTRIAL
4. COMMERCIAL
5. GOVERNMENT (MUNICIPAL)
6. OTHER

REFUSE TYPE
1. MIXED
2. GARBAGE
3. RUBBISH
4. BULKY OBJECTS
5. ASHES
6. OTHER

VEHICLE TYPE
1. COMPACTOR (FRONT LOADER)
2. COMPACTOR (REAR LOADER)
3. COMPACTOR (SIDE LOADER)
4. ROLL-OFF DUMP (CONTAINER)
5. TRANSFER TRAILER
6. DUMP
7. STAKE BODY
8. PANEL
9. STATION WAGON
0. PRIVATE

CAPACITY (CUBIC YARDS)
1. 1-2
2. 3-5
3. 6-10
4. 11-19
5. 20-23
6. 24-28
7. 30-39
8. 40-49
9. 50-65
0. 66+

WEATHER
1. CLEAR
2. SHOWERS
3. RAIN
4. SNOW

TEMPERATURE
0. BELOW 0
1. 0-20
2. 21-30
3. 31-40
4. 41-50
5. 51-60
6. 61-70
7. 71-80
. 81-90
. ABOVE 90

WIND
1. CALM
2. BREEZY
3. STRONG

Void Test

CREDIT CUSTOMER'S SIGNATURE

Figure 3. An example of the weight tickets used at the pyrolysis plant.

TABLE 4. RECEIVING AREA TIME STUDY*

Test No.	1	2	3	4	5	6	7	8	9	Average
	Time (Seconds)									
Travel, enter plant to scale	50	45	48	49	53	51	67	61	61	54
Weighing	25	35	32	40	42	22	28	47	24	33
Travel, scale to dump	15	-	26	19	12	24	23	17	23	20
Dumping	105	-	384	212	163	256	219	227	250	227
Travel, tipping floor to plant exit	45	-	40	37	-	33	28	48	35	38
Total time in plant	240	-	530	357	-	386	365	400	393	381

* No traffic delays during tests, trucks travelling unobstructed through plant.

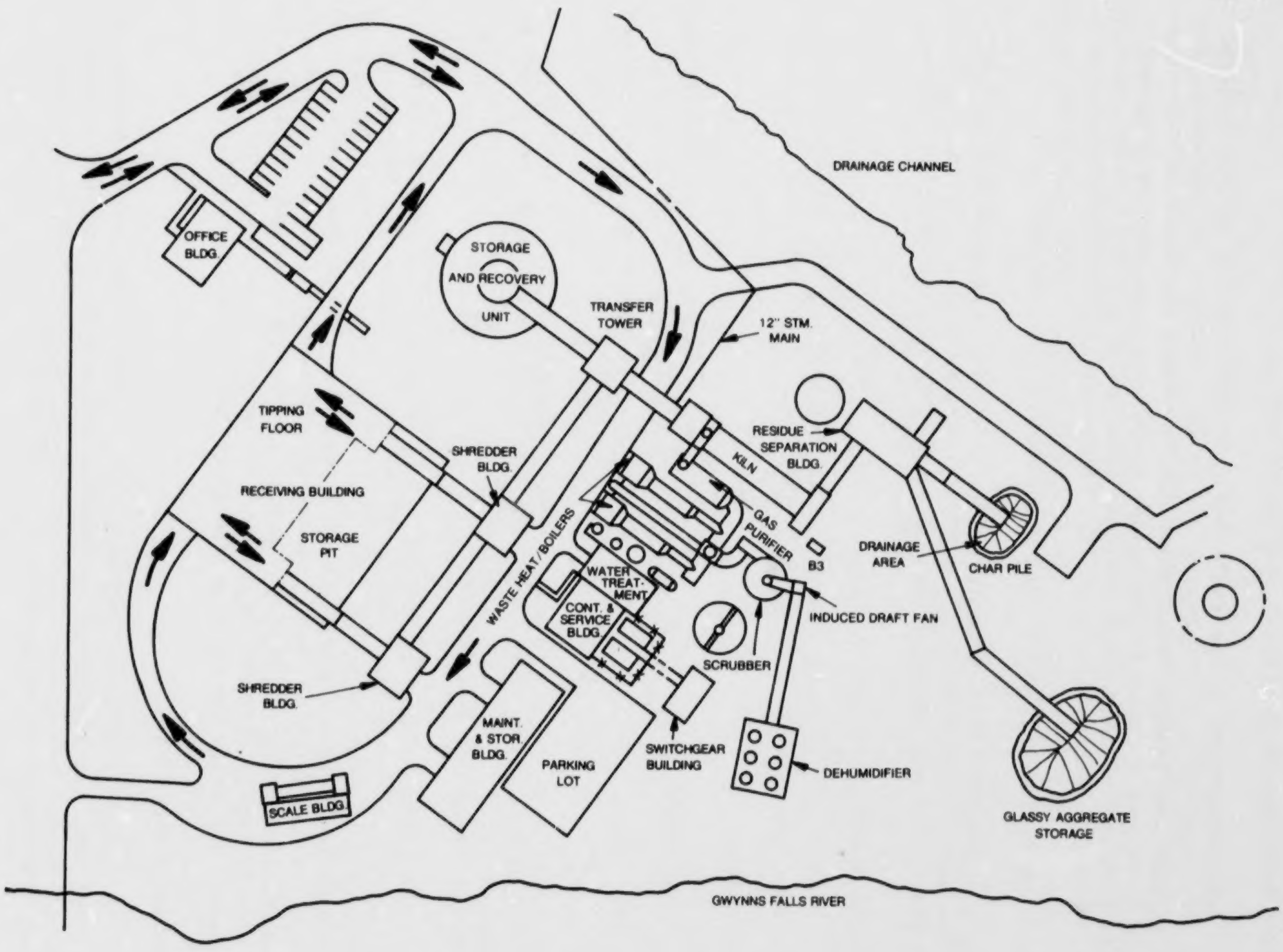

DRAINAGE CHANNEL
OFFICE BLDG.
STORAGE AND RECOVERY UNIT
TRANSFER TOWER
12" STM. MAIN
TIPPING FLOOR
RECEIVING BUILDING
STORAGE PIT
SHREDDER BLDG.
SHREDDER BLDG.
RESIDUE SEPARATION BLDG.
KILN
GAS PURIFIER
B3
DRAINAGE AREA
CHAR PILE
WASTE HEAT/BOILERS
WATER TREAT-MENT
CONT. & SERVICE BLDG.
SCRUBBER
INDUCED DRAFT FAN
MAINT. & STOR. BLDG.
PARKING LOT
SWITCHGEAR BUILDING
DEHUMIDIFIER
GLASSY AGGREGATE STORAGE
SCALE BLDG.
GWYNNS FALLS RIVER

Figure 4. Refuse truck routing plan.

better means for the operator-driver transactions. In addition, the communication between the scale and tipping floor operators could be improved considerbly by relocating the scale house closer to the tipping floor or by interconnecting the two sites with telephones or radios.

The temperature in the scale house is difficult to control because of the poor insulation of the four glass walls. Rather than increasing the capacity of the heating and cooling system within the house as was done, it would be better to enclose the walls, except the area for the proposed sliding window or door, with adequate insulating materials since the operator has no need for extended visibility. Moreover, the operator's equipment should be positioned close to the proposed window or door since the operator wastes much time and motion with the existing arrangement.

The Toledo Scale Company provides maintenance service for the scale system under a contract with the City. Thus far, the scale has performed satisfactorily and required only minor maintenance and calibration.

Tipping Floor

After being weighed, the loaded trucks drive to the receiving building and enter the tipping floor area to discharge their load into a storage pit.

Description

The tipping floor (Figure 5) is a 51 m (168 ft) by 24 m (80 ft) concrete slab which is elevated 4.4 m (14.5 ft) above the bottom of the storage pit. On the tipping floor beside the storage pit are the truck bays which are aligned and equally separated except for the one at each end. Each of the two end bays, which extend further toward the storage pit center, is equipped with a chute for direct dumping onto an apron conveyor. The two conveyors, one at each end, are recessed in the storage pit floor and extend across the width of the pit. At the other eight bays, the trucks simply dump their loads on the storage pit floor.

The tipping floor was designed to handle up to 50 trucks per hour. Even if the two end truck bays remain inoperative, as discussed below, the experience to date indicates that the tipping floor will be able to handle the peak loads if the plant were to operate at design capacity. The tipping floor has one operator whose responsibilities are (1) to direct each truck to a particular bay so that an orderly traffic flow is maintained and the refuse is evenly distributed in the storage pit, and (2) to move truck spillage and other debris from the floor into the storage pit.

Operating Experience

Originally, each bay had steel-pipe stops to prevent the trucks from backing into the storage pit. However, because their clearance was designed for an empty truck, they were consequently severely damaged and were replaced with concrete stops about 30 cm (12 in.) high.

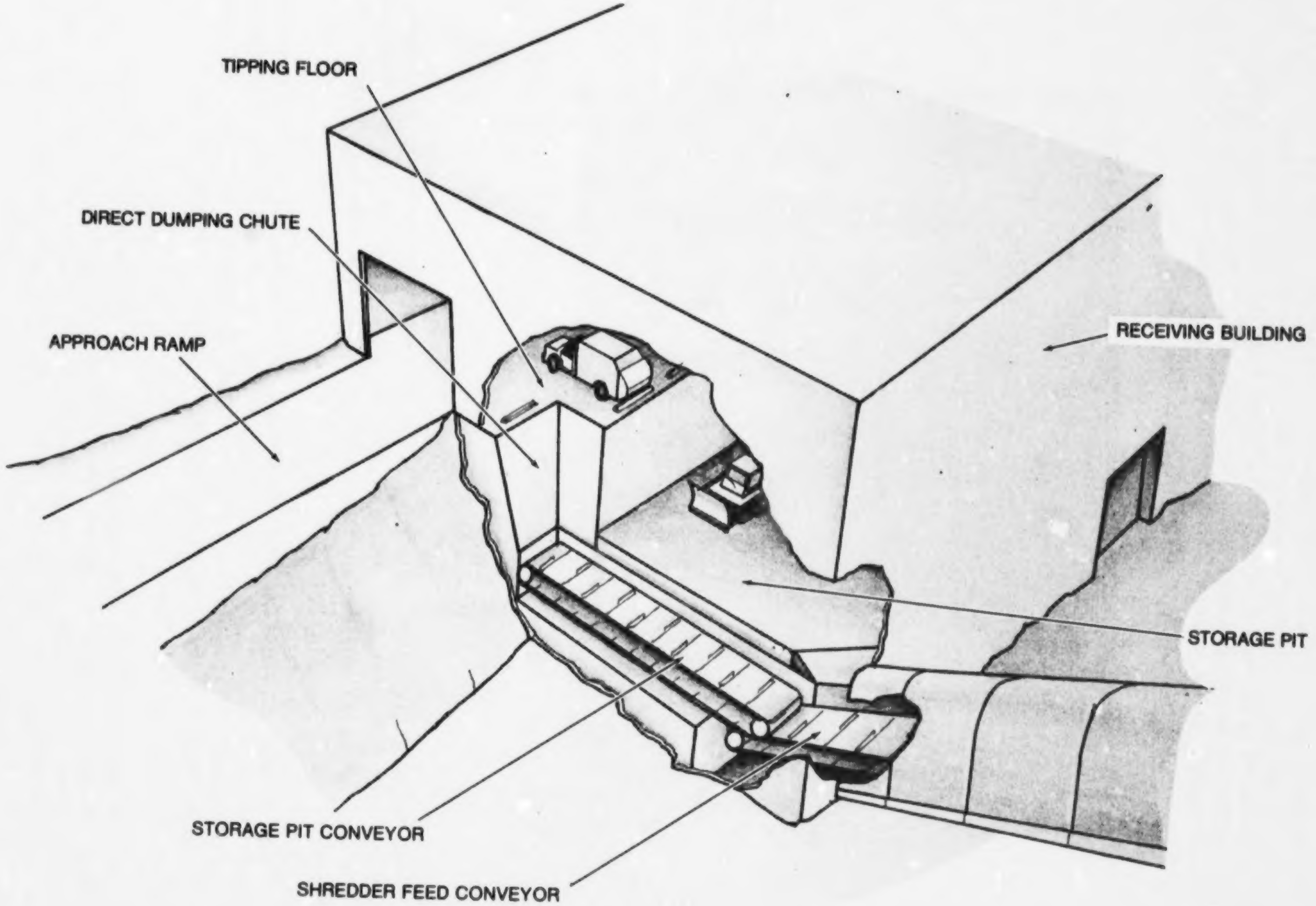

TIPPING FLOOR
DIRECT DUMPING CHUTE
APPROACH RAMP
RECEIVING BUILDING
STORAGE PIT
STORAGE PIT CONVEYOR
SHREDDER FEED CONVEYOR

Figure 5. Schematic of the receiving building.

The two end bays, those that are each equipped with a chute for direct waste dumping (Figures 5 and 6) onto the apron conveyor, are no longer used because of frequent waste jamming at the bottom of the chute. The jamming was due to the chute design, that is, the convergent sides of the chute produced too small a cross-sectional area for the waste to pass. The decision to not use these bays was further motivated because the direct dumping allowed certain loads containing large concentration of low density materials (paper or hay) to enter the shredder directly (not mixed) and subsequently plug the shredder, material-handling equipment, or both.

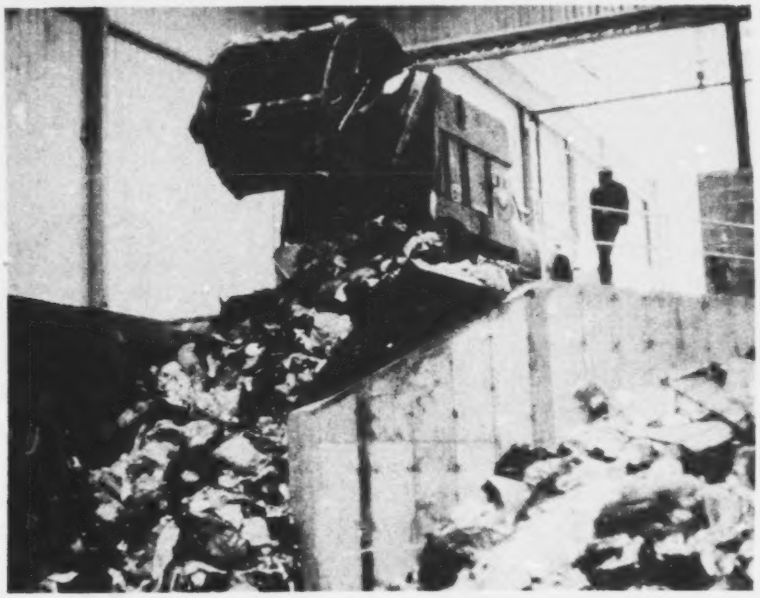


Figure 6. Refuse truck discharging to the direct dump chute.

The tipping floor in the area of the direct dump bays had settled, likely because the fill had not been compacted enough before the floor itself was poured. However, after the floor was restored, there has been no further settling.

Because of its insufficient clearance, a hanging fire wall installed between the tipping floor area and the adjacent area above the storage pit has been damaged by the opened rear doors of the trucks. To prevent such damage would require increasing the clearance from 5 m (16 ft) to 6 m (20 ft) or removing the wall.

In the plant design, the tipping floor and storage pit areas were enclosed to protect people and equipment from inclement weather and to prevent wind from scattering refuse. Exhaust vents in the roof coupled with the large open doorways for the trucks were to suffice for the exiting of dust and exhaust fumes. However, as discussed in the environmental section of the report, there has been a excessive build up of dust and fumes in the tipping floor area which could be sufficiently reduced by installing exhaust fans in the existing vents.

The truckers' use of the portable toilets on the tipping floor has frequently disrupted and delayed the flow of traffic. Consequently, a comfort station should be made available in an area where the parked trucks would not interfere with the traffic flow.

Storage Pit

The storage pit provides the means for receiving and temporarily storing the refuse.

Description

The reinforced concrete storage pit, shown in Figures 7 and 8 is a 34 m (112 ft) by 24 m (80 ft) wide floor with 4.4 m (14.5 ft) high walls. The pit volume therefore is 3590 m (126,000 ft.^{3}). On the basis of loose refuse with a 160-kg/m^3 (10-lbs/ft^3) bulk density, the pit has a design capacity of 590 Mg (650 tons) of waste. As mentioned above, an apron conveyor at each end of the pit is recessed in the pit floor and extends across the width of the pit. Since these conveyors are considered part of the size reduction system, they are detailed later.

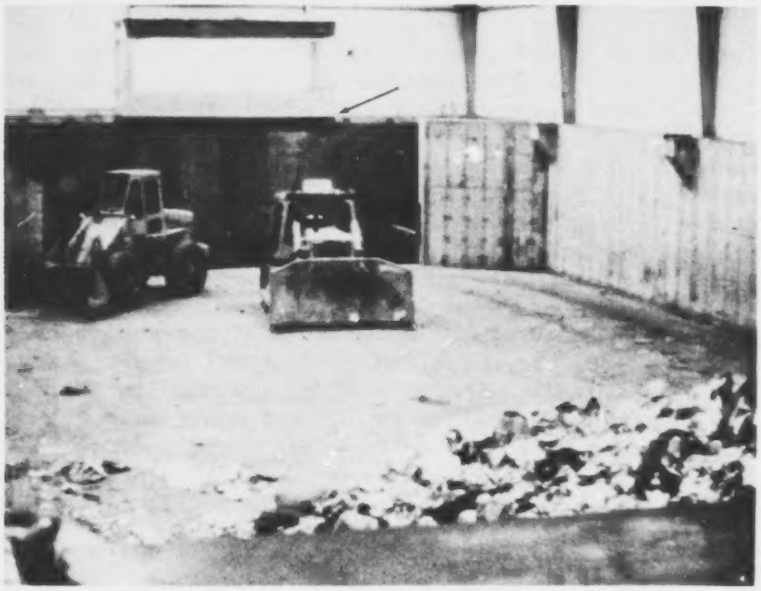


Figure 7. Empty storage pit.

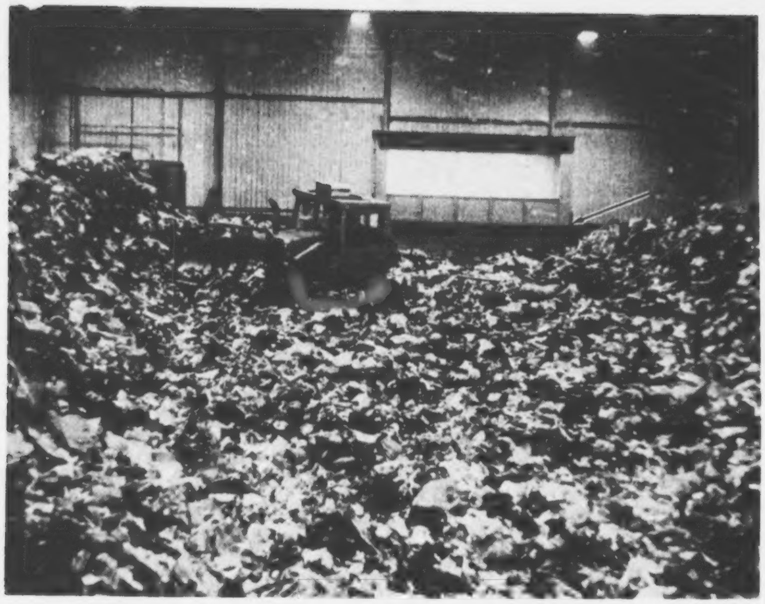


Figure 8. Full storage pit.

A fire prevention system for the pit consists of a fire cannon at each end of the tipping floor and an overhead dry pipe sprinkler system. If a fire occurs, the system automatically activates and stops the pit conveyor to prevent the spread of fire. The fire cannons are also used to clean loose debris from the tipping floor and residual waste from the emptied pit floor. Any water entering the pit is removed by two sump pumps installed beneath each pit conveyor. In addition, a ground-level opening provides access for the pit operations, maintenance, and cleaning, and an air-conditioned enclosure adjacent to the pit serves as an observation booth for visitors.

During the development of the material-handling equipment system to be used in the storage pit, the costs and operational capabilities of overhead cranes, such as those used in incinerator receiving pits, were evaluated against those of bulldozers. Since two cranes would be required to keep each of the conveyors loaded whereas one bulldozer would suffice to load both, and since the costs for the cranes would be 5 to 10 times more than those for the bulldozers, the bulldozers were selected as the preferred type of material-handling equipment. Nevertheless, crane mounts were installed to permit, if later desired, retrofitting the building with cranes.

Operating Experience

As stated above, the storage pit has a design capacity of 590 Mg (650 tons) of refuse based upon its 3590-m^3 (126,000-ft^3) volume and a bulk density of 160 kg/m^3 (10 lbs/ft^3) for loose refuse. Operational data for such refuse have verified this design capacity. However, operational data for the refuse compacted by the bulldozers have indicated a pit capacity of 1100 Mg (1200 tons) for packed refuse. Since test data for well-compacted refuse show bulk densities up to 480 kg/m3 (30 lbs/ft^3), the average of 320 kg/m^3 (20 lbs/ft^3) for the bulk densities of the loose and the well-compacted refuse would yield a pit capacity of 1200 mg (1300 tons). These computations, therefore, substantiate a pit capacity of 1100 Mg (1200 tons) for packed refuse.

Thus far the pit operation has been capable of attaining the designed refuse reception rate of 180 Mg per hour (200 tph) and the pit has required no maintenance other than cleaning.

SIZE REDUCTION MODULE

The size reduction module has the primary function of shredding the heterogenous solid waste stream into pieces of relatively uniform size to facilitate the material handling and thermal processing of the waste.

Although not indicated in Figure 9, whose shaded areas represent the size reduction module, the first components to contribute to the size reduction function are two bulldozers assigned to the storage pit. Operating one at a time and working from the top of the pile to compact the refuse as well as to protect the pit floor, the bulldozers push the refuse toward and onto two conveyors, one at each end of the pit. The storage pit conveyors discharge their waste load onto shredder feed conveyors which in turn discharge the waste into parallel shredders. Finally, the shredded refuse discharged from each shredder falls onto an inclined vibrating pan, called the shredder discharge conveyor, to complete the module components.

The shredders have not been able to attain their design capacity because of the frequent stopping of the feed conveyors. These stops were due to the uneven waste loading which overloaded the shredder which, in turn, shut down the feed conveyors. Initially, shredder explosions caused a few shutdowns until the shredder venting was modified and a Fenwall explosion suppression system was installed.

Storage Pit Bulldozers

The bulldozer functions are to distribute the accumulating piles of refuse below the truck bays within the storage pit for maximum temporary storage and, concurrently, to ultimately move the refuse onto the two storage pit conveyors. In turn, these conveyors transport the refuse to shredder feed conveyors, as discussed below. The normal operational procedure calls for one bulldozer operating at a time in the storage pit. To both protect the concrete floor of the pit and perform initial refuse compacting, the bulldozer works from the top of the pile to spread successively accumulating layers as the bulldozer pushes the refuse toward the two pit conveyors.

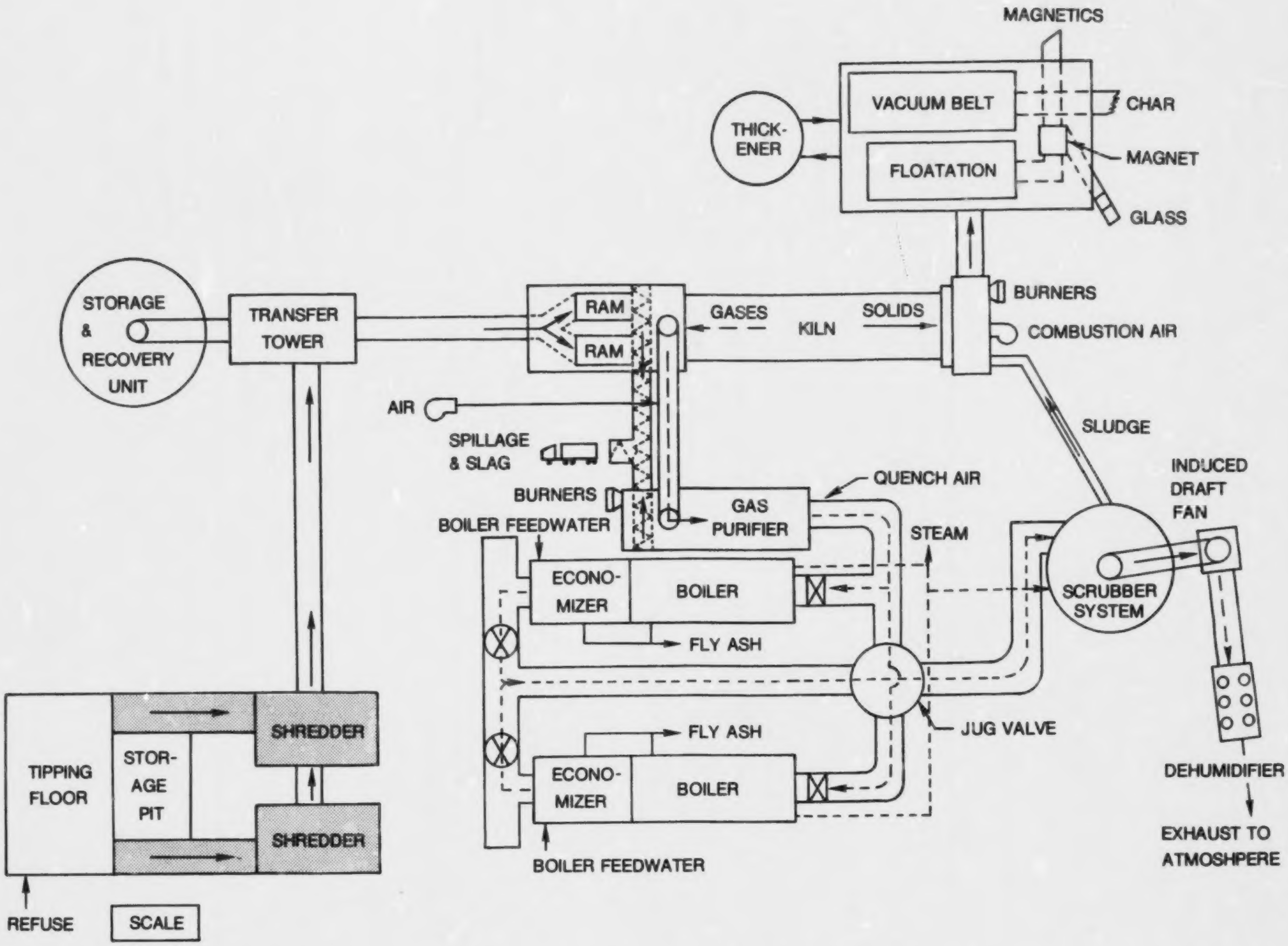

MAGNETICS
VACUUM BELT
CHAR
THICK-
ENER
MAGNET
FLOATATION
GLASS
STORAGE
&
RECOVERY
UNIT
TRANSFER
TOWER
RAM
RAM
GASES
KILN
SOLIDS
BURNERS
COMBUSTION AIR
AIR
SLUDGE
SPILLAGE
& SLAG
QUENCH AIR
INDUCED
DRAFT
FAN
BURNERS
GAS
PURIFIER
STEAM
BOILER FEEDWATER
ECONO-
MIZER
BOILER
SCRUBBER
SYSTEM
FLY ASH
TIPPING
FLOOR
STOR-
AGE
PIT
SHREDDER
SHREDDER
FLY ASH
JUG VALVE
ECONO-
MIZER
BOILER
DEHUMIDIFIER
BOILER FEEDWATER
EXHAUST TO
ATMOSHPERE
REFUSE
SCALE

Figure 9. Size reduction module (shaded area).

Description

The bulldozers are Allis-Chalmers Model HD11D track-type vehicles equipped with 8.4 m^3 (300 ft^3) landfill blades for a design pushing capacity of 160 Mg (175 tons) of solid waste per hour. The bulldozer blades and tracks are covered with rubber guards to reduce wear and damage on the pit floor.

Operating Experience

The original schedule for bulldozer operation called for a 16-hour day during a 6-day week. This schedule was based on the shredder design capacity of 45 Mg (50 tons) of refuse per hour and a post shredder storage capacity of 1815 Mg (2000 tons). Since the past shredder storage is not presently in use, the daily operation was increased to 24 hours.

The rubber guards covering the blades and tracks have required frequent repair and replacement because of their heavy wear. To prevent overheating and to reduce internal wear, the bulldozers must be cleaned of dust and debris, as shown in Figure 10, after each 8-hour operation. In addition (because of dust accumulating between the radiator and its splash guard), excessive overheating of the bulldozers has required removing the splash, blade, and heat guards from the bulldozers. Although the bulldozer maintenance performed by the City Center Garage is generally adequate with apparently reasonable costs, much operational time is lost because of transporting them to and from the garage and the difficulties in coordinating maintenance schedules with the garage personnel. The time lost in cleaning and maintaining the bulldozers is particularly critical when the bulldozers must be operated continuously to maintain the required feed flow on the pit conveyors.

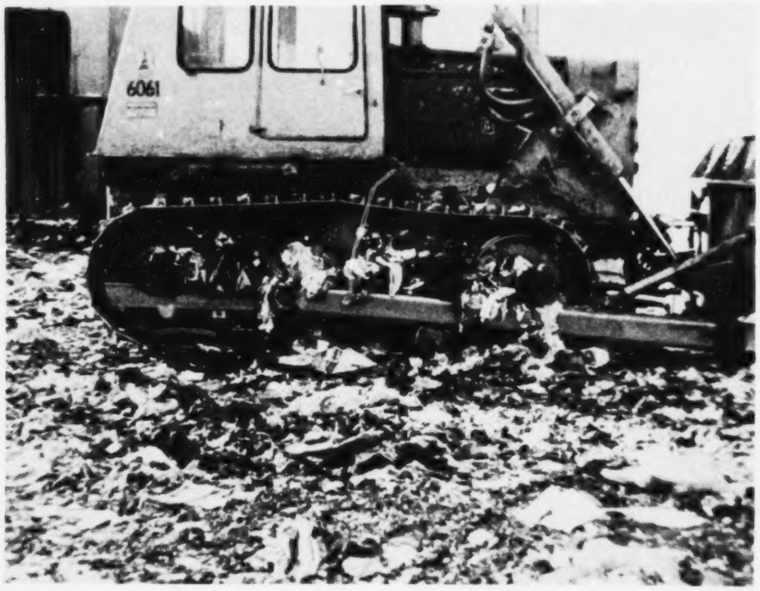


Figure 10. Storage pit bulldozers.

The efficiency of the storage pit operations depends on the bulldozer operator's competence, his ability to see the waste levels on the pit conveyors, and his communication with the chief plant operator in the control room who starts and stops the conveyors. Since there is no direct means of communication between the control room and the bulldozer, a control room messenger must walk over to the bulldozer operator to inform him of the chief plant operator's plans and directions.

Initially, the bulldozer operator frequently overloaded the conveyors because the accumulating refuse layers rose to heights which obscured his vision. To correct this condition, flashing lights were installed in the pit to indicate when the conveyors were operating and a leveling bar was installed over each conveyor to prevent the waste level from exceeding the maximum height for normal operation. However, since some conveyor jamming and failures due to overloading have continued, a mirror or television system might be installed to further guide the bulldozer operator.

Storage Pit and Shredder Feed Conveyors

As mentioned above, the wastes loaded onto the storage pit conveyors are transferred directly onto the shredder feed conveyors. The latter conveyors in turn discharge the waste into two shredders contained in the adjacent shredder buildings. The pit and feed conveyors are interlocked so that the pit conveyor cannot run unless the feed conveyor is operating. Figure 5 shows a side view of the pit and feed conveyor alignment.

Description

Both the storage pit and the shredder feed conveyors, shown in Figure 5, are Rexnord piano-hinged 1.8-m (6-ft) wide apron conveyors. They are constructed of carbon steel with apron pan cleats every third flight, a continuous bottom pan, overlapping side wings, side chains, bushed steel rollers, a frame, roller chain tracks, and guides (Figure 11).

Designed to run at a fixed speed of 1.5 meters per minute (5 fpm), the storage pit conveyor at each end of the pit is 15.5 m (50 ft) long and is installed in a hopper recessed 1.2 m (4 ft) below the pit floor to facilitate the conveyor loading from the floor. The hopper is formed by a steel wall from the conveyor to the pit floor level on one side and a steel wall from the conveyor to the tipping floor level on the other side (see Figure 12). As previously discussed, the direct dump chutes at the tail end of each pit conveyor are not being used because of the chute jamming and the passage of some low density and unshreddable materials which damaged or plugged the shredder and the material handling equipment. Therefore, only bulldozers are currently loading these conveyors.

Designed to run at a fixed speed of 4.6 m per minute (15 fpm), the shredder feed conveyors are each 24 m (80 ft) long, have a 30° elevation angle, and are so aligned with the storage pit conveyors that the pit conveyor discharge falls vertically onto the tail end of the feed conveyors.

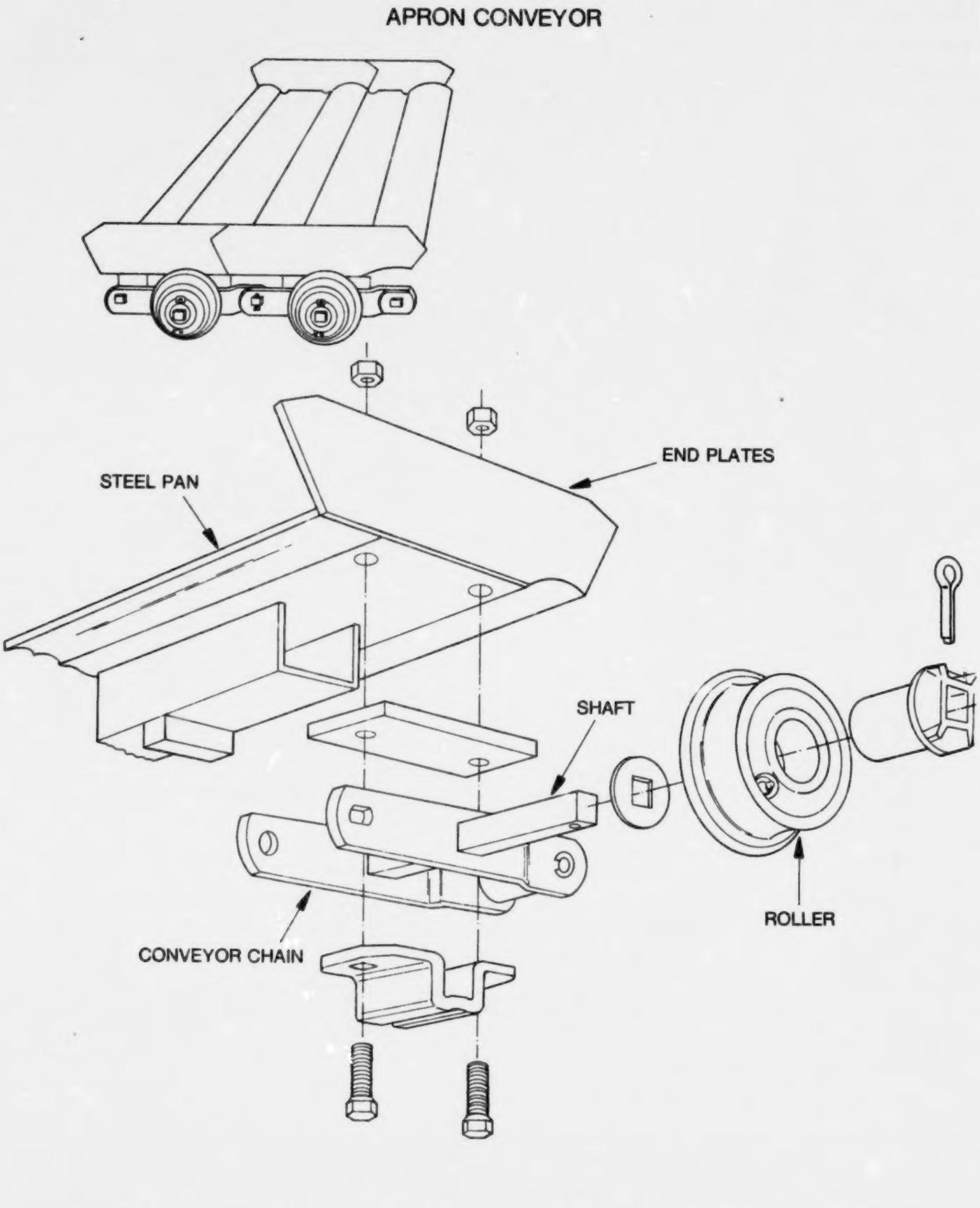

APRON CONVEYOR
STEEL PAN
END PLATES
SHAFT
ROLLER
CONVEYOR CHAIN

Figure 11. An exploded view of the apron conveyor.

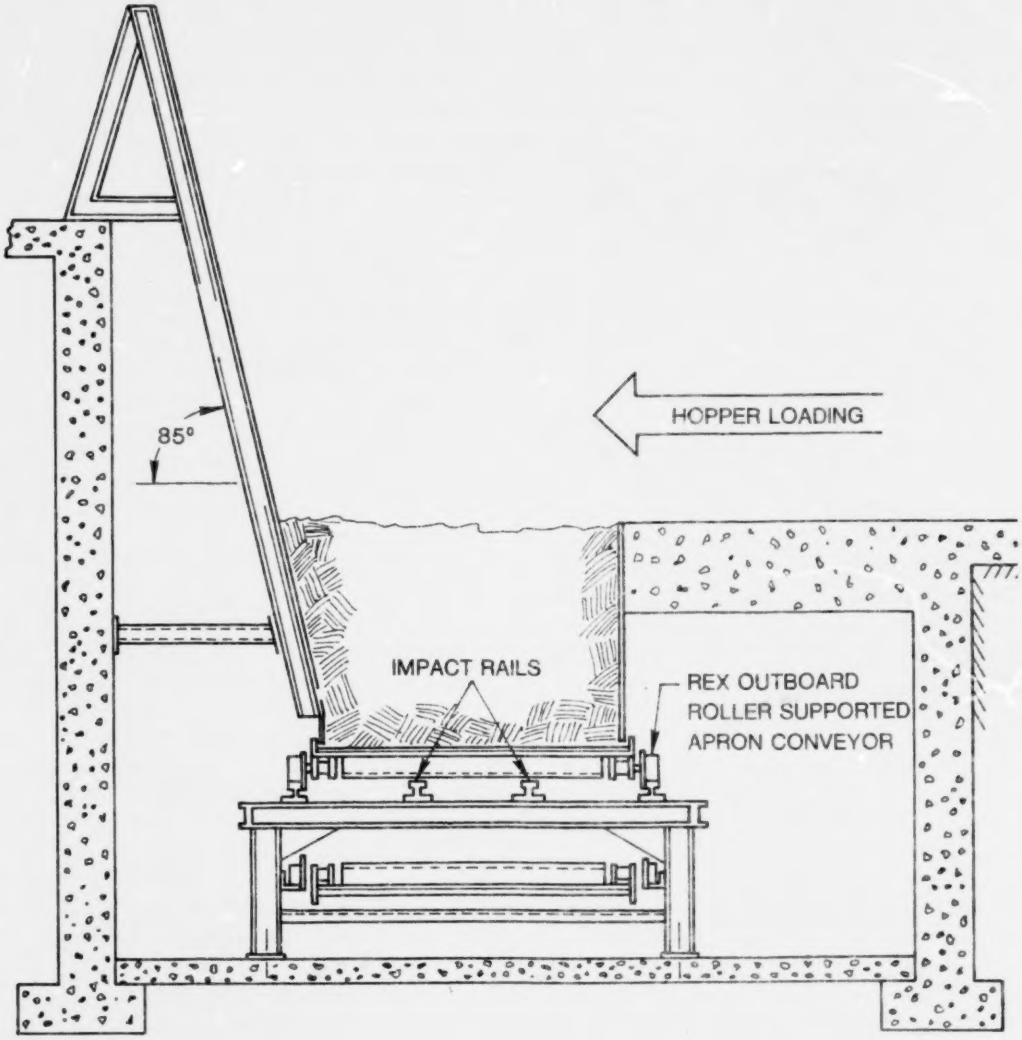

HOPPER LOADING
85°
IMPACT RAILS
REX OUTBOARD
ROLLER SUPPORTED
APRON CONVEYOR

Figure 12. A typical section through a storage pit conveyor.

Each feed conveyor is enclosed in a sheet metal gallery which connects the receiving and shredder buildings. The feed conveyors have continuous 1.1-m (3.5-ft) high-skirts on both sides and pans with vertical pusher plates as shown in Figure 13.

Operating Experience

To enable the chief operator in the main control room (Figure 14) to operate the pit conveyors with greater flexibility, and especially to maintain a constant load on the conveyors (as measured by the shredder current) as the bulk density of the refuse varies, the designed fixed speed of 1.5 m per minute (5 fpm) was changed to a variable speed from 0 to 3 m per minute (0 to 10 fpm). Since the storage and recovery unit is currently being bypassed, the feed rate of refuse to the thermal processing area can be regulated by varying the speed rate of the pit conveyors.

The following provisions were instituted to improve the bulldozer operator's efficiency in loading the pit conveyors to the proper level: (1) flashing lights were installed to inform the operator when the conveyors are running; (2) lines were painted on the hopper walls to indicate the maximum refuse levels on the conveyors; and (3) a fixed bar was installed above each of the storage pit conveyors to reduce the peaks of trash on the conveyors. After several geometric configurations were tested, a bar with a rounded bottom edge facing the oncoming refuse flow was selected. However, when the waste level rises on a bar so that the jamming back pressure overloads the conveyor, the shear pin connecting the motor and drive sprockets breaks to protect the conveyor from damage. Such shear pin failures frequently require completely removing the bar to clear the jam. In addition to the bulldozer operator not allowing the waste to exceed the desired level, such jammings could be minimized by replacing the fixed bar with a tensioned one which would move away as the back pressure approaches an overloaded condition.

One of the pit conveyors sustained major damage when a solid steel object jamming in a pinch point caused the overstress and failure of a conveyor link. Since the shear pin was improperly installed in the drive socket, the motor continued to drive the conveyor while other links as well as pans were damaged.

Waste accumulating in the return run of the shredder feed conveyors had frequently compacted and jammed the conveyor with the subsequent breakage of the shear pin and extensive downtime. To minimize such failures, a drop-out chute was installed on the return pan so that the refuse retained on the return run would fall onto the shredder discharge conveyor.

Another frequent cause of extensive feed conveyor downtime was due to the failure of the chain links on the side of the pans. These links connect the pans on the conveyor and engage with the drive sprocket to move the conveyor. As waste wedged between the links and the drive sprocket, it caused the links to cantilever (Figure 15) and, consequently, to be overstressed to failure. The failures of the link caused a successive

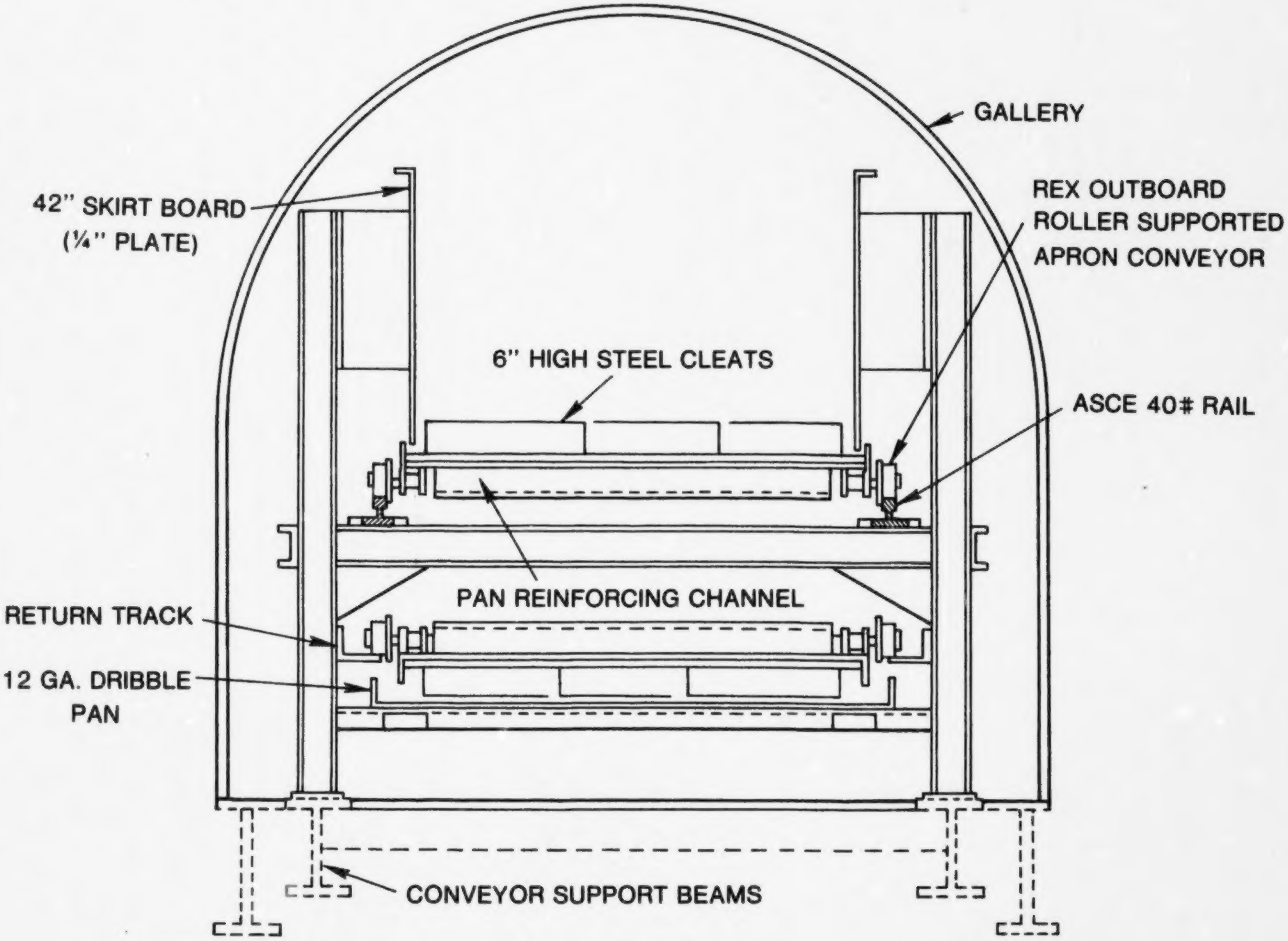

GALLERY
42" SKIRT BOARD (¼" PLATE)
REX OUTBOARD ROLLER SUPPORTED APRON CONVEYOR
6" HIGH STEEL CLEATS
ASCE 40# RAIL
PAN REINFORCING CHANNEL
RETURN TRACK
12 GA. DRIBBLE PAN
CONVEYOR SUPPORT BEAMS

Figure 13. A typical section through a shredder feed conveyor.

Reproduced from
best available copy.

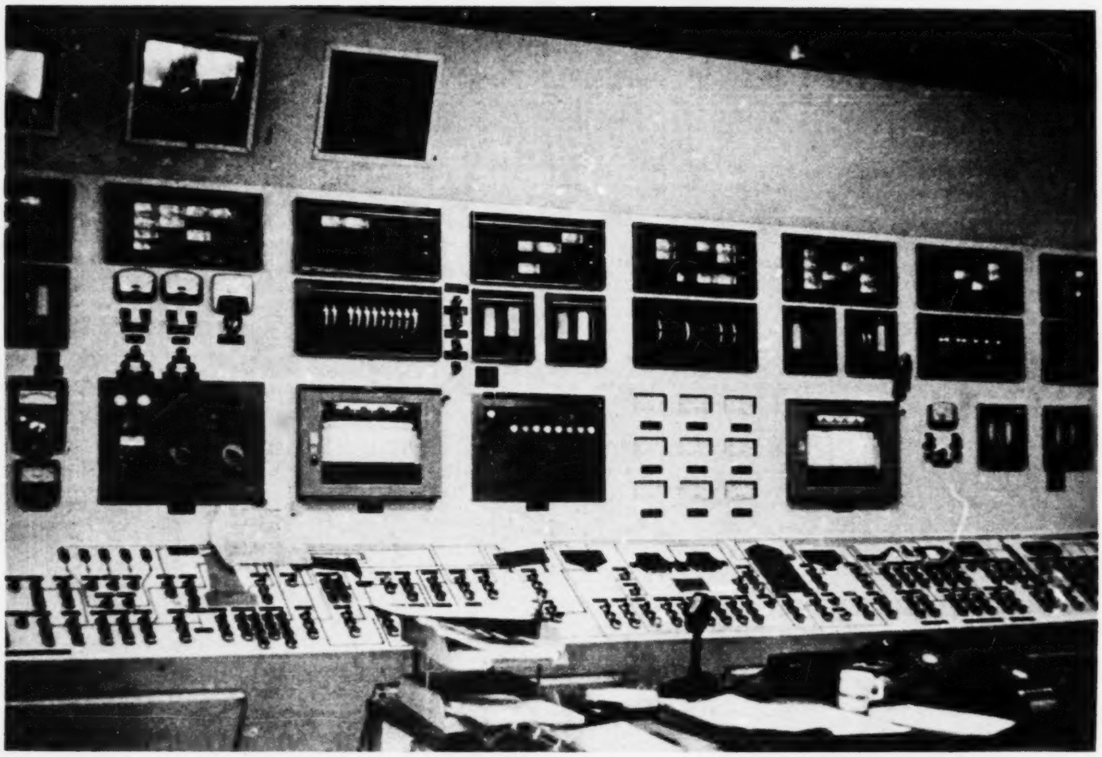
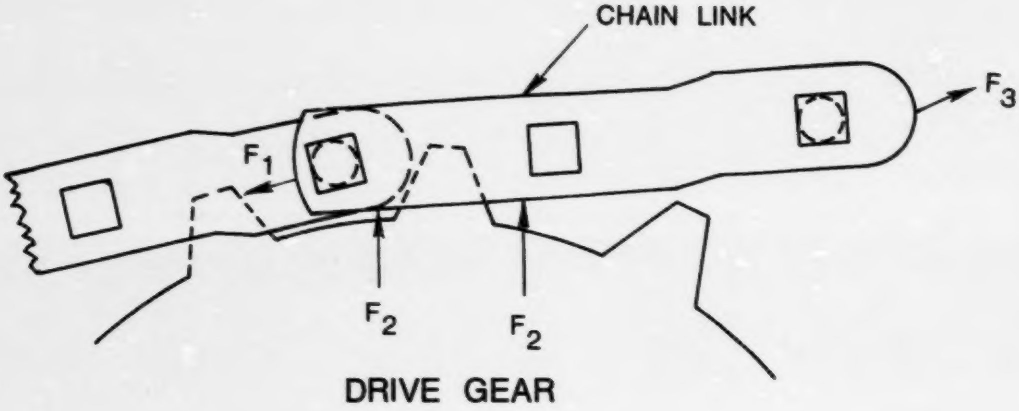
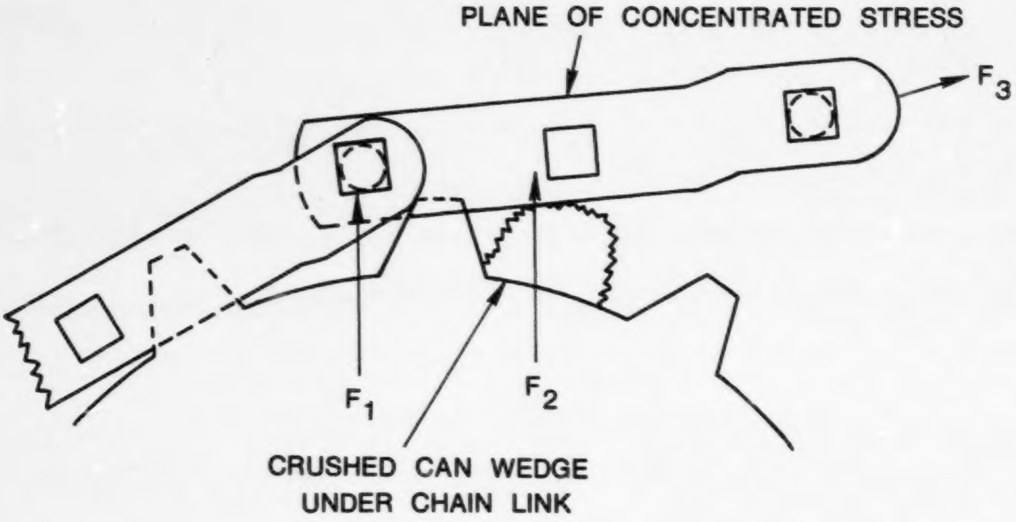


Figure 14. Control panel in main control room.

STRESS CONCENTRATION ON CHAIN LINK


CHAIN LINK
F_3
F_1
F_2
F_2
DRIVE GEAR

NORMAL LINK SUPPORT


PLANE OF CONCENTRATED STRESS
F_3
F_1
F_2
CRUSHED CAN WEDGE UNDER CHAIN LINK

OBJECT WEDGED BENEATH LINK

Figure 15. Link failure on shredder feed conveyor.

overstressing and failure of other links. After the head sprocket and chain were enclosed within a steel guard to prevent waste from accumulating within them, the chain links remained intact.

Because of waste jamming at the point where the pit conveyor transfers the refuse to the feed conveyor, the original 122-cm (48-in.) long pusher plates, which had been installed on the feed conveyor to keep waste from sliding down its 30° incline, were replaced by 45-cm (18-in.) long staggered plates to minimize the jamming. In addition, pusher plates were installed on the pit conveyor to prevent waste from bridging in the hopper.

To prevent the spillage and wear due to waste moving behind the sidewall plates of the conveyors, rubber skirts were bolted to both sideboards of the four conveyors and installed at each of the head and tail pulleys. While the skirts have effectively restricted the spillage, they sustain severe wear and damage.

Spillage at the gap between the two conveyors was especially severe since the pit conveyor, particularly its pusher bars, pushed the waste in such a way that it tended to fall into the recessed pit below the conveyors. To prevent this spillback, the tail ends of the two feed conveyors were retrofitted with steel plate gates, which pivot on their horizontal axes, and with gate stops, so that the gates swing only in the travel direction, to prevent waste from falling backwards. Although the gates were initially only marginally effective, design improvements have made them satisfactory.

Since the continuous bottom pan of the pit conveyor carries any carryover waste down the return run, the tail end of the conveyor was enclosed so that the waste would pass around the tail pulley and then be forced up the conveyor by the pusher plates. This modification prevents refuse accumulation at the tail end.

The fire protection system so interlocks the pit and feed conveyors that whenever it detects burning waste in one conveyor, it automatically stops both conveyors to prevent the fire from spreading to the other conveyors. All material-handling conveyors in the other sections of the plant are similarly interlocked. The pit conveyor also interlocks with the feed conveyor so that a a stoppage of the latter automatically stops the former. However, if the shear pin in the drive sprocket of the feed conveyor fails, the interlock is defeated and the motor continues running. This design deficiency could be remedied by installing a zero speed sensor on the tail pulley of the feed conveyor whose signal would feed to the interlock control.

The feed conveyor also interlocks with the shredder so that two conditions must be satisfied for the feed conveyor to continue running: (1) the shredder must be operating to prevent its being plugged, and (2) the shredder amperage must be below the maximum set by the chief operator in the control room to prevent shredder overloading. Although the setting is generally at 110 amps, it can be varied from 0 to 140 amps.

Television cameras were installed with a direct view of the feed conveyor and an view of the pit conveyor so that the monitor in the control room could detect unshreddable objects in the feed stream, conveyor overloading, and shear pin failure.

Maintenance

Because of the damage caused by grit and large metal pieces in municipal refuse, the operational disruptions due to waste spillage and jamming and the continued severe service with its extreme wear, the pit and feed conveyor requires extensive cleaning and maintenance. In summary, the rubber sidewall skirts must be serviced frequently; shear pins, rollers, axles, and bushings must be replaced periodically; and chain tensions and alignments must be adjusted routinely. Table 5 lists the preventive maintenance schedule for the pit and feed conveyors.

Shredders

Installed in parallel buildings, the two shredders receive refuse from shredder feed conveyors (discussed in the last section), reduce most of it to particles smaller than 15 cm, and discharge all the waste to an inclined vibrating pan (shredder discharge) conveyor directly under each shredder.

As detailed later, the shredder operation consists basically of a horizontal rotor swinging 28 freely pivoting hammers toward the downward flow of refuse which falls on one side of the rotor. The combined hammer torque and centrifugal forces pulverize brittle materials such as glass; compact ductile materials such as steel cans; and tear shearable materials such as paper, wood, and textiles. Particles smaller than 15 cm pass through 15-cm-square opening in a semicylindrical grate which is concentric with the lower half of the hammer rotation. Particles passing through the grate fall directly onto the vibrating pan. Particles larger than 15 cm are forced upward and around the swinging rotor for repeated hammering until they either pass through the grate openings, are ultimately thrown into an oversized chute, or are separately removed from the shredder. This chute is built into an access door on the side opposite the refuse downfall. The chute entrance, which is 30 cm wide (originally 60 cm), entends along the rotor length at a constant height above the sweep of the hammer rotation. The chute exit is also above the vibrating pan.

The reduction in the refuse particle size with the consequent increase in waste surface area accelerates the subsequent thermal processing; produces a more homogeneous refuse for easier waste handling, storage, and recovery; and enhances vector (insect and rodent) control by distributing the smaller food waste particles throughout the refuse. However, some of the disadvantages of shredding are some pulverized glass enters the kiln-off gas as particulate and some causes severe wear of the motor bearings, the conveyor idlers, floor, bucket chains, and drag conveyor equipment in the storage and recovery unit.

TABLE 5. APRON CONVEYOR PREVENTIVE MAINTENANCE SCHEDULE

Daily

Inspect gearmotor unit for oil leaks or unusual sounds.

Weekly

Adjust the chain tension while the chain is in motion to allow a slight sag in the chain under the headshaft sprockets.
Check the flights for loose bolts and material buildup; repair or replace all damaged flights.
Replace any damaged chain at once; never use new chain with old sprockets or new sprockets with old chain.
Inspect pans; check apron and pan bead opening for proper spacing or distortion.
Check housekeeping, buildup causes excess wear.
Inspect the centers around the chain, load carrying, and tension members of the apron conveyor unit:
    Check sidebar inner faces for wear caused by misalignment.
    Check for missing cotter pins.
    Look for frozen rollers.
    Inspect around pots of chain for wear.
    Inspect sprockets for alignment and check excessive tooth wear.
Lubrication:
    Chain reducer
    (Winter - Paradene 430)
    (Summer - Paradene 1000)
    Drive chain (Paradene 430).
    Flat chain (Paradene 430).

Monthly

Grease all bearings and outboard rollers (LiEP2).
Oil the flap gates on the conveyors (Paradene 430).

Bi-monthly

Check oil and grease for contamination.

Semiannually

Change oil in gear reducer and examine backstop for worn or damaged springs on shredder feed conveyors.
Change grease at pillow block bearings with plugs out and conveyors running.

CONTINUED

TABLE 5. (Continued)

Change drive chain oil (Paradene 430).
Grease motor (LiEP2).
Check motor, alarm, and interlock circuit, operation of gear change system push buttons and drive motor.
Lubricate and inspect pull cord switch.
Check operation of speed indicator pulser and meter.

Annually

Grease vari-drivers (LiEP2).
Megger motors.

Description

As shown in Figure 16, each shredder is a Jeffery Model 990 horizontal shaft rotary hammermill which is powered by a Louis Allis 800-hp motor with a V-belt drive train. The hammermill is enclosed on all four sides by reinforced steel plates on the outside and identical, but removable, wear plates on the inside with an access door on the side opposite the refuse inlet. The area for the refuse downfall extends, as an explosion vent, without any horizontal obstruction from the hammermill through the roof of the shredder building. The semicylindrical grate with 15-cm (6-in.) square openings, as mentioned above, consists of hardened steel sections and forms the bottom of the shredder.

The rotor is made of steel, measures approximately 1.8 m in diameter, 2.3 m in length, and has a drive system consisting of 16 rubber V-belts. A shaft extending between each of the four paired rotor arms supports seven hammers. Each hammer is a rectangularly shaped, hardened-steel block with two symmetrical holes in the sides. The hammer weighs 82 kg (180 lbs.) and measures approximately 42 cm (17 in.) long, 25 cm (10 in.) high, and 15 cm (6 in.) wide. Since each hammer can be installed with one hole and then the other and turned 180° while using each hole, it has four impact faces. Figures 17 and 18 show used and rebuilt hammers.

The major auxiliary equipment for each shredder consists of a hydraulic system, a pumped oil lubricating system, a dust collection system, and an explosion suppression system.

The hydraulic system supplies pressure to operate the access door for cleaning and maintenance and the pin puller (the mechanism to extract and insert the mounting pins for the hammers). The major system components

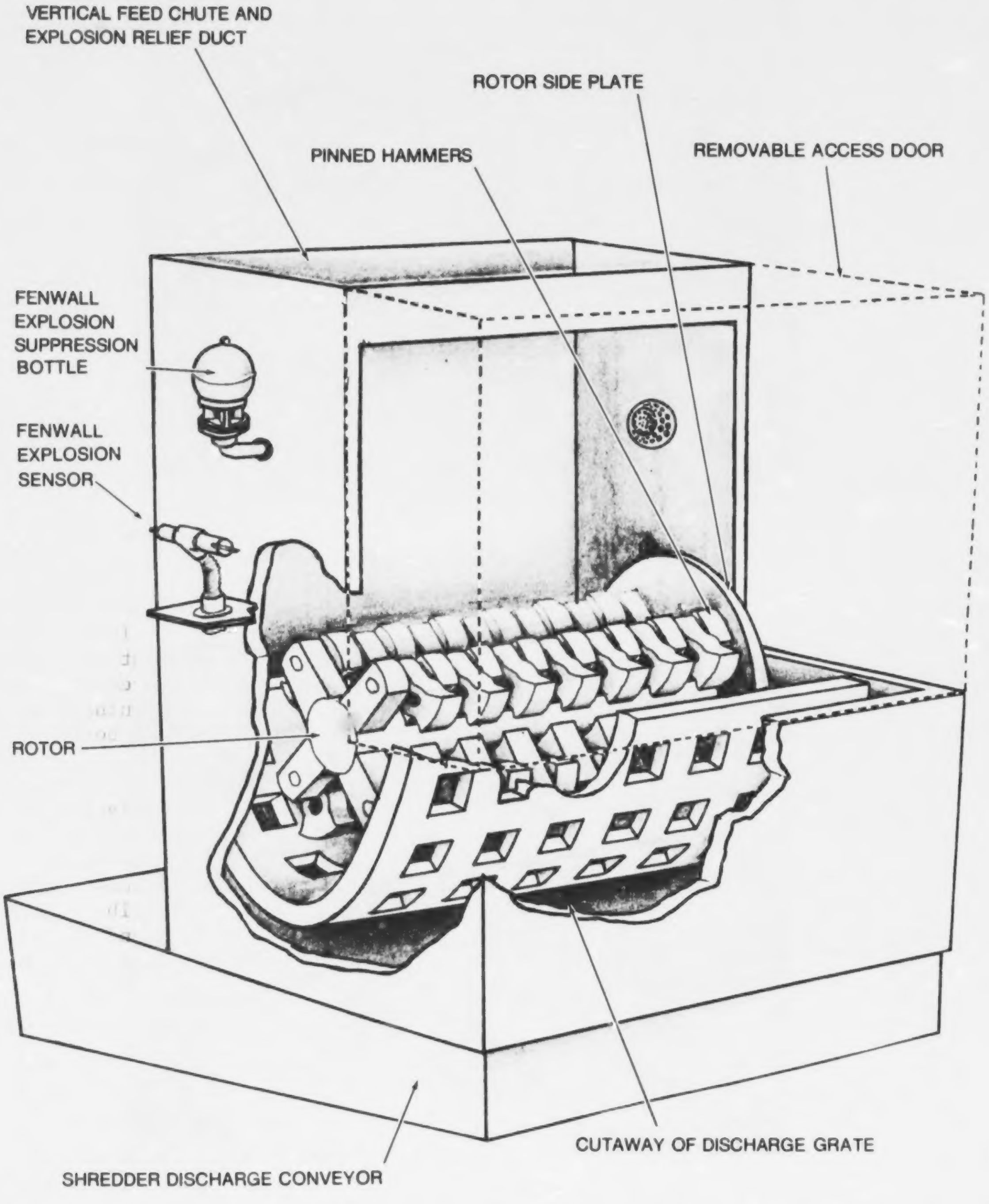

VERTICAL FEED CHUTE AND EXPLOSION RELIEF DUCT
ROTOR SIDE PLATE
PINNED HAMMERS
REMOVABLE ACCESS DOOR
FENWALL EXPLOSION SUPPRESSION BOTTLE
FENWALL EXPLOSION SENSOR
ROTOR
CUTAWAY OF DISCHARGE GRATE
SHREDDER DISCHARGE CONVEYOR

Figure 16. Schematic of a hammermill shredder.

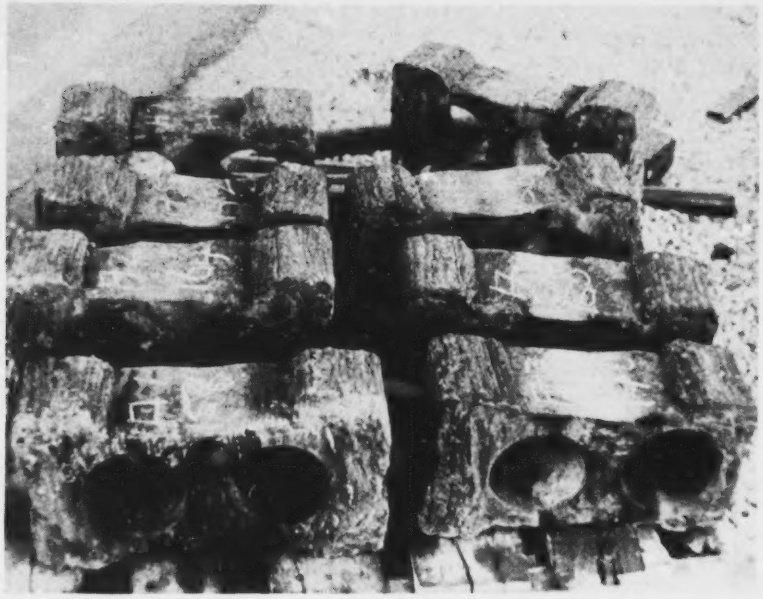


Figure 17. Rebuilt shredder hammers.

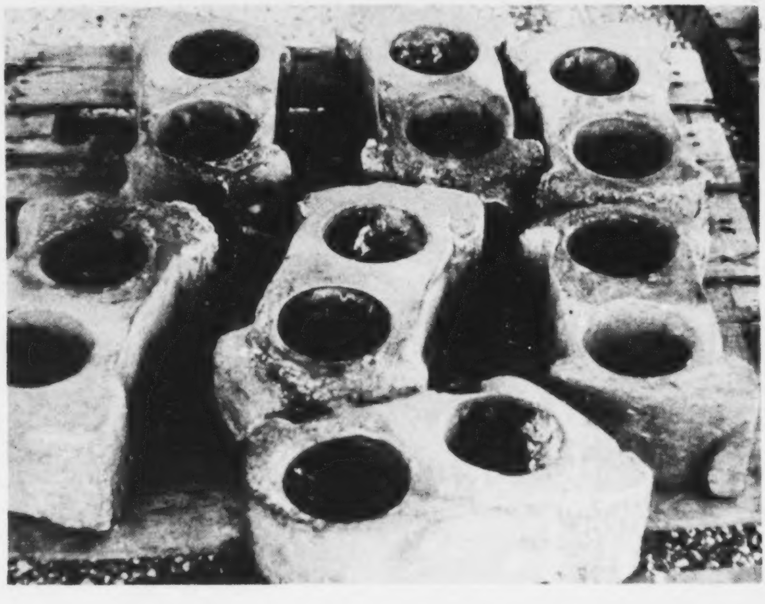


Figure 18. Worn shredder hammers.

include: (1) a 15-hp pump which has the twofold function of opening and closing the access door and of manipulating the mounting pins for hammer changes, (2) a 2-hp pump to hold the access door closed during shredder operation, and (3) an oil heater and heat exchanger to keep the fluid viscosity constant as the ambient temperature varies.

As detailed later, the shredders are interlocked with the shredder motor, the hydraulic system, the lubricating system, the access door, the rotor-vibration monitor, and an explosion suppression system.

The pumped oil lubricating system supplies lubricating oil to the two main shredder bearings at each end of the rotor. These bearing must be well lubricated because of their critical function and need to sustain extreme loads. The major system components include a bearing oil pump and an oil heater and heat exchanger to maintain a constant oil viscosity as the ambient temperature varies.

Each shredder has dust pick-up points which connect to the plant dust collection system. The plant dust collection system and the explosion suppression system are both detailed later.

Operating Experience

The removable wear plates on the inside of the reinforced steel sides that enclose the shredder are still the original units. Although they evidence minor wear, these plates, as intended, have provided a sacrificial wear surface and ensured the structural integrity of the shredder. In addition, the refuse downfall opening extending to the roof for the venting of explosion pressures has remained free of horizontal obstructions as shredder modifications were installed.

The 15-cm (6-in.) square openings in the grate were intended to pass particles with a nominal 7.5-cm (3-in.) size. Although the stream characterization data, detailed later, shows that the nominal shredded refuse size is less than 2.5 cm (1 in.), some pliable materials, such as plastics and textiles, larger than 15 cm (6 in.) have been sufficiently deformed to pass through the openings, and other large materials have entered the downstream conveyors from the oversize chute in the shredder. Such large materials, particularly textiles, have impeded the subsequent waste handling and processing operations.

The original hammers were intended to be rebuilt after shredding about 1815 Mg (2000 tons) of waste with each of the four faces. The restoration consisted of two phases: the first to reshape the hammer to its original configuration by using a standard weld material, and the second to apply two coatings of a hard facing material. Because of the excessive wear rates of the hard facing material, an abrasive-resistant material was applied as a third coating. Although the third coating increased the hammer life, it did not prove cost effective.

As a result of the foregoing experience, the restorable hammers were replaced with disposable ones made of special alloys which impart a hardness throughout the hammer rather than primarily on the surface. A comparison of the restorable and disposable hammer wear rates shown in Table 6, reveals that the disposable hammers have a much longer life. Because of excessive wear during the periods shown in Table 6, the useful life of the restorable and disposable hammers is 1815 Mg (2000 tons) and 3450 Mg (3800 tons) per face respectively.

TABLE 6. SHREDDER HAMMER WEAR*

Period	Hours per face	Mg per face
	Restorable Jeffrey Hammers	
11/29/76 - 12/18/76	104.5	3099
12/16/76 - 12/23/76	89.0	1929
01/09/77 - 01/24/77	103.5	2788
01/25/77 - 02/27/77	141.5	3243
03/01/77 - 03/12/77	130.0	2910
12/12/76 - 12/23/76	119.0	2939
01/09/77 - 01/21/77	97.5	2520
01/22/77 - 02/07/77	96.5	1650
02/23/77 - 03/10/77	141.0	3159
03/11/77 - 03/19/77	109.0	2991
04/25/77 - 05/03/77	59.0	1905
04/04/77 - 05/09/77	54.0	1715
05/10/77 - 05/15/77	58.5	1860
Average	100.2	2516
	Disposable ESCO Hammers	
04/25/77 - 05/08/77	140.0	4354

* City Daily Operation Reports and Maintenance Log.

In addition to increased hammer life, the disposable hammer appears to require less power to shred a given mass of refuse, as shown in Table 7.

The cost comparison of the restorable and the disposable hammers depends on the number of times that the former can be rebuilt. Because of decreasing structural strength, the manufacturer recommends that the maximum number of hammer restorations be limited to two. A cost comparison of the two types of hammers revealed that the new hammers have proved to be more economical.

TABLE 7. SHREDDER POWER CONSUMPTION

Date	Hammers	Average Amperes	Mg/hr.	kwh/Mg	$/Mg*
3/20/77	Worn Jeffrey	67.55	28.1	9.8	0.32
3/17/77	Rebuilt Jeffrey	70.97	32.4	9.1	0.30
4/27/77	New ESCO	62.48	35.4	7.4	0.24
5/07/77	Worn ESCO	52.4	27.2	8.0	0.26
5/09/77	New ESCO	67.57	38.1	7.4	0.24

* $0.033 per kw-hr.

As intended, the rotor belt drive system has protected the rotor by slipping or breaking when unshreddable materials have jammed the rotor. Although the rotor has operated at high wear rates and has occasionally stopped abruptly, it has never locked nor had a major operational deficiency.

The original 60 cm (2 ft) width of the oversize chute was reduced to 30 cm (1 ft) so that the larger materials would be further shredded before being thrown into the chute. However, since textiles and paper can now more readily plug the smaller chute, unshreddable materials frequently accumulate within the shredder.

Although the dust collector system has been augmented by installing gaskets and skirts at all shredder openings, excessive dust and waste particles continue to fill the shredder building and threaten the operation of the shredder motors. Dust accumulating on the ventilation screens and heat transfer fins impair the fin effectiveness causing the motors to overheat. Moreover, the dust itself has a serious fire and explosion potential.

Explosion Suppression System

Two types of explosions occur in shredders. One type, which accounts for most of the explosions, is due to the deflagration of combustibles such as dust and fumes, accumulating in the shredder ductwork. The other type is caused by the detonation of such individual objects as gas cylinders and dynamite.

After an explosion had severely damaged one of the shredders, the venting system was modified and a Fenwall explosion suppression system was installed in each shredder. Besides a structural reinforcement, the shredder vent was redesigned to change the original converging sidewalls to diverging sidewalls for a greater venting capacity. In addition, a cage with a roof was installed above the vent outlet on the roof of the shredder building. The cage was intended to prevent metals from projecting through the vent and rain from entering the vent.

Designed to suppress only explosions caused by deflagrations, the Fenwall system consists primarily of paired pressure sensors and extinguisher bottles attached to the exterior surface with ports into the interior (Figures 16 and 19). To ensure optimum protection, these pairs were installed at strategic locations throughout the shredder body, the outlet duct, the dust collection unit, and the shredder discharge duct. Each extinguisher bottle, a spherical metal vessel, contains nitrogen gas as the dispersing medium, which is under a pressure of 2070 kPa (300 psig), and hydrochlorobromide liquid, the principal suppressent agent. When the pressure wave preceeding the main shock wave of a deflagration strikes the sensor, the sensor activates the extinguisher bottles. Then the nitrogen gas, which discharges at a high rate, projects and scatters the hydrochlorobromide throughout the shredder. While the nitrogen depletes the oxygen to reduce the combustion, the hydrochlorobromide reacts with the radicals in the flame zone to suppress the deflagration before it generates the explosive force of its main shock wave.

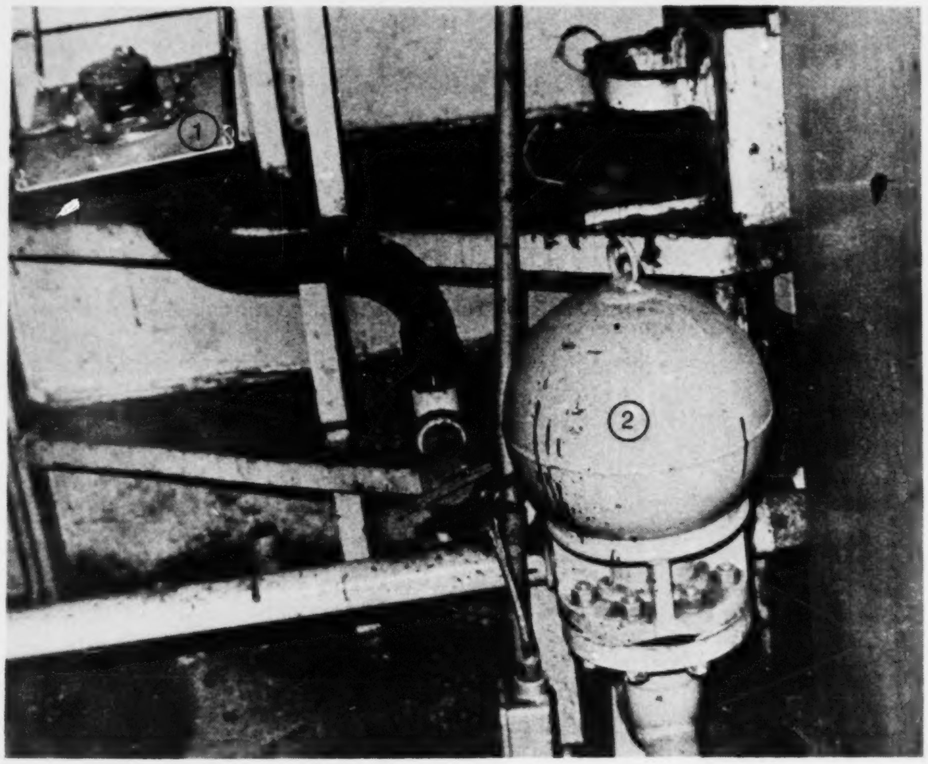


Figure 19. Fenwall sensor[1] and extinguisher.[2]

After each of several sensor activations, with rarely any evidence of explosive effects, a Fenwall representative called to the site has investigated and reported the cause of the sensor activation and restored the system for continued service. The Fenwall Company guarantees that the total system downtime after each activation will be less than 36 hours. One activation was due to refuse plugging and compressing air in the detector tube, and two others, which occurred without the discharge of the extinguisher bottles, were due to either a system malfunction or a maintenance deficiency.

Since the modification of the shredder vents and the installation of the Fenwall systems, the shredders have not been damaged by explosions. However, tests have shown excessive dust accumulation in the pipes connecting the Fenwall system to the shredder after about 250 Mg (275 tons) of waste has been processed through the shredder. Such dust accumulations impede the functioning of the sensors and the discharge of the extinguisher bottles. While some pipes have been protected with dust covers, others that cannot be so protected (because of their location) must be manually cleaned after each shift. In order to eliminate this problem, a design has been submitted for an automatic air purge system to prevent excessive dust accumulations anywhere in the Fenwall system.

Shredder Capacity

Although each shredder was designed to handle 45 Mg (50 tons) of wastes per hour with an instantaneous maximum rate of 68 Mg (75 tons) per hour, the maximum and average rates observed during the current study were 41 and 27 Mg (45 and 30 tons) per hour, respectively (Table 8). The lower rates were due to plant personnel running the shredders far below capacity because of the frequent shredder overloads which stopped the feed conveyors. A plot of the shredder motor current in Figure 20 indicates the motor tendency to become overloaded as indicated by the transient current peaks. When the feed conveyor overloads the shredder, an interlock stops the conveyor until an automatic restart with a 2-minute delay reactivates the conveyor. By reducing the delay time to 10 seconds, the shredder processing rate can be raised to between 36 and 41 Mg (40 to 45 tph) per hour. The shredder capacity has also increased when refuse retained in the storage pit has been so compacted and sheared by the bulldozer operation that it enters the shredder with a smaller particle size and greater bulk density. Like the feed conveyors, the shredders have been handling wastes whose bulk densities are less than those designed for.

The probability plot of the shredder current in Figure 21 indicates that the shredder operation is generally in an unloaded condition that should permit increasing the shredder feed rates. However, because of the motor tending to become overloaded with transient waste peaks, a higher feed rate would require increasing the horsepower of the drive unit or distributing the waste more evenly over the feed conveyors.

Shredder Interlocks

Each shredder is equipped with the following interlocks to ensure its safe and efficient operation. Three separate interlocks protect the motor as

TABLE 8. SHREDDING RATE*

DATE	Mg/hr	DATE	Mg/hr
7/23/76	24.2	1/13/77	17.7
7/24/76	28.9	1/14/77	26.0
7/25/76	25.1	1/15/77	26.5
7/27/76	24.5	1/16/77	11.0
7/28/76	23.0	1/18/77	28.5
7/29/76	24.2	1/19/77	32.0
8/ 5/76	25.9	1/20/77	26.6
8/ 6/76	26.5	1/21/77	20.2
8/ 7/76	36.3	1/23/77	28.7
8/ 8/76	35.2	1/24/77	15.5
11/ 7/76	31.1	2/ 1/77	21.2
11/ 8/76	31.3	2/ 2/77	30.8
11/12/76	25.8	2/ 4/77	35.3
11/16/76	28.2	2/ 6/77	20.7
11/17/76	23.6	2/ 6/77	24.7
11/18/76	32.8	2/ 7/77	31.8
11/27/76	27.5	2/23/77	22.3
11/28/76	23.8	2/24/77	26.5
11/29/76	27.2	2/25/77	25.0
11/30/76	21.5	2/26/77	23.4
12/ 8/76	21.0	2/27/77	26.0
12/10/76	34.0	3/ 1/77	26.7
12/11/76	31.6	3/ 2/77	26.6
12/12/76	28.4	3/ 3/77	28.8
12/14/76	28.2	3/ 4/77	29.5
12/15/76	15.0	3/ 5/77	31.3
12/16/76	31.0	3/ 6/77	35.9
12/17/76	31.2	3/ 8/77	29.6
12/18/76	19.6	3/ 9/77	30.1
12/19/76	18.2	3/10/77	32.1
12/20/76	32.1	3/11/77	27.9
12/21/76	27.3	3/12/77	32.8
12/22/76	17.6	3/13/77	30.0
12/23/76	19.1	3/14/77	33.4
1/ 9/77	29.6	3/15/77	28.3
1/10/77	22.4	3/16/77	33.3
1/11/77	31.7	3/17/77	32.0
1/12/77	22.5	3/18/77	28.3
		3/19/77	33.1

Mean	26.98
Standard Deviation	5.24

*Source: City Daily Operation Summary

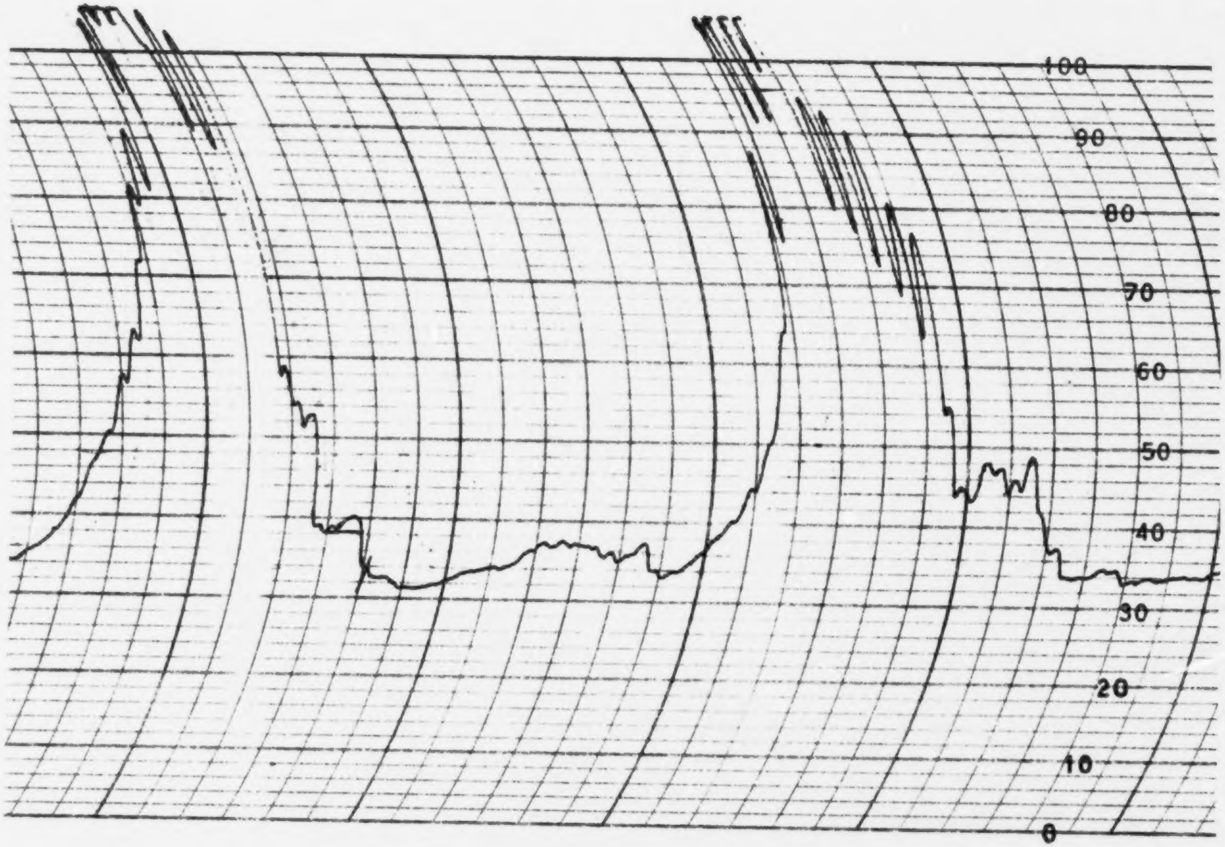


Figure 20. A recording ammeter graph of shredder current.

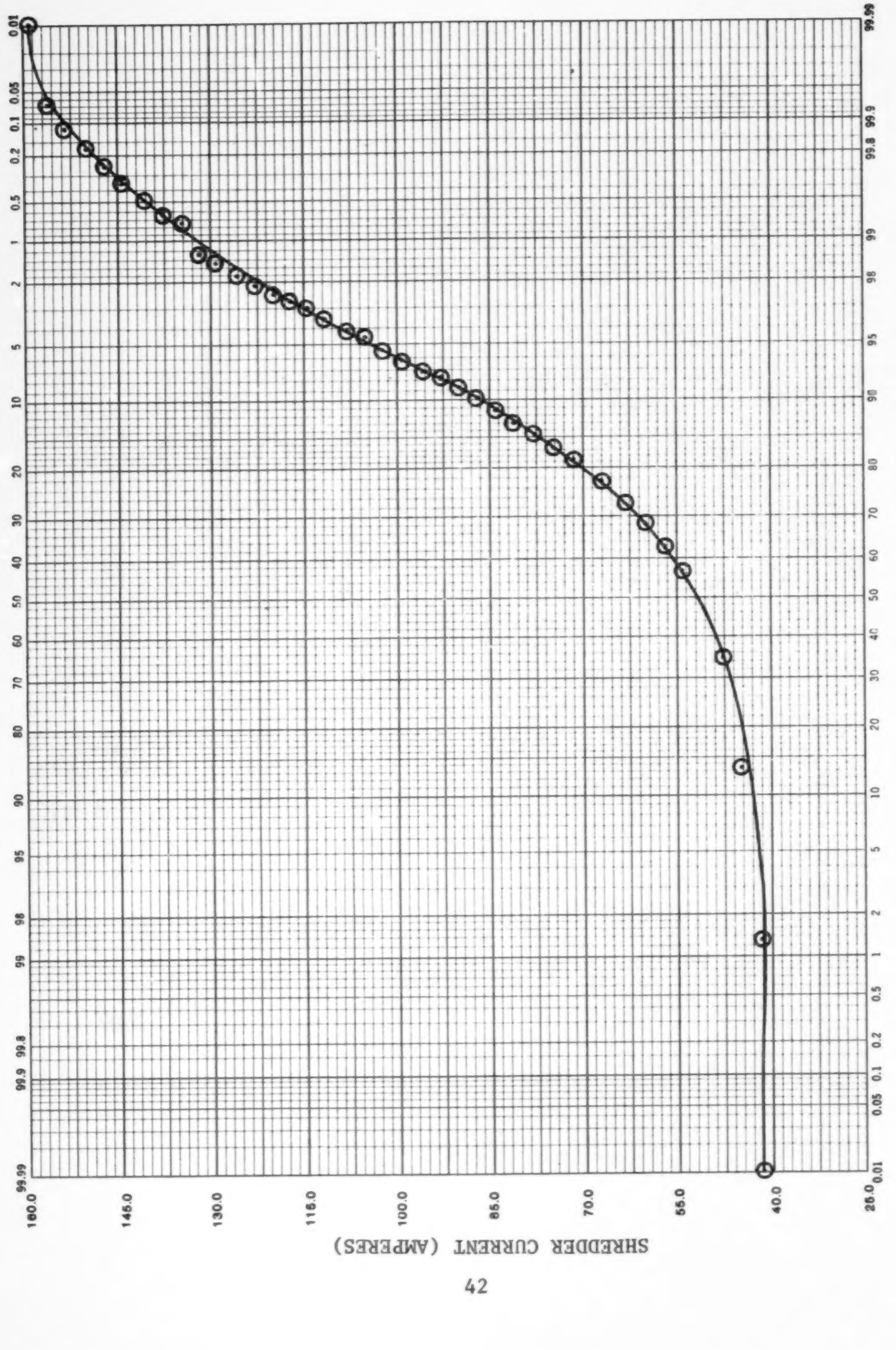


Figure 21. Probability plot of shredder current.

follows: One interlock stops the feed conveyor when the motor current is above 110 amps for more than 6 seconds, and the second and third interlocks shut off the motor when the current is above 130 amps for more than 12 seconds and above 200 amps for more than 2 seconds, respectively.

In order to ensure proper lubrication of the shredder bearings, there are two interlocks: one shuts down the shredder when the lubricating system is not functioning and the other does the same when the oil temperature exceeds 81°C (175°F). In order to ensure that the access door is securely closed for shredder operation, there are two interlocks: one to make certain that the hydraulic system is applying the required pressure on the door and the other to ensure that a door locking pin is in position. Still another interlock ties in with the rotor vibration monitor so that the shredder operation is stopped whenever the vibration becomes excessive.

When the Fenwall system was installed, an interlock was added to allow shredder operation only when the system is armed. To prevent jamming the shredder and transporting burning refuse from one conveyor to another, the feed and discharge conveyors are so interlocked that the shutdown of the latter stops the former.

Maintenance

Because of the abrasives, particularly broken glass and sheared metal, and their high velocities in the shredder, the hammer, grate, rotor, and sidewall plate surfaces obviously sustain severe wear.

Since the hammers have the highest wear rates, they require the most maintenance. During the current study, turning or rotating the hammers required 4 hours with three men, replacing them required 8 hours and three men, and the restoration of a restorable hammer required 6 hours. The replacement of one set of grates after 63,500 Mg (70,000 tons) of waste had been processed required 8 hours with three men. Although the rotors and sidewall plates have not yet been replaced, it is estimated that their effective lives will handle 100,000 and 200,000 Mg (110,000 and 220,000 tons) of refuse, respectively The rotor replacement will require about 16 hours with three men.

The belts, which require routine adjustment to maintain the proper tension, must be replaced periodically. Operating time has been lost because of drive deficiencies due to inadequate maintenance that allowed belts to slip and become damaged and because of the eccentric loading on the motor-mounting platform that shifted the drive assembly out of alignment.

Except for the sensor ports which the plant personnel rod out after each shift, the explosive suppression system is maintained by the Fenwall Company.

Before the initial start-up, the rotor bearings had to be replaced because of their having been idle for several months. One of the drive shafts on the shredder motor required remachining and another had to be replaced when a misalignment caused its bending.

The shredder preventive maintenance schedule is shown in Table 9.

TABLE 9. SHREDDER PREVENTIVE MAINTENANCE SCHEDULE

Daily

Open main motor safety switch.
Clean with a fire hose:
  Replace hammers cracked at the eye.
  Replace all broken pins.
Cracks in grate bars and spiders should be noted in log. A large crack should be repaired immediately.
Check wear on side liners.
Replace broken bolts, all bolts should be tight.
Check for lube and hydraulic leaks.
Clean around the bearing housing.
Check V-belts for tension + wear (1" deflection with 50 lbs. pull).
Check bearing lube oil level. (Paradene X1000)

Weekly (40-50 hours)

Clean all welds.
Check for wear on spider ends, hammers, liners, etc.
Check frame welds.
Change filters after first 40-50 hours.
Check hydraulic level. (Paradene 430)
Check all drive components for damage or excess wear.
Clean dirt and dust off drive motor, lubrication, and hydraulic systems.
Investigate anything abnormal.
Check vibration.
Check coupling alignment.
Balance flow indicator.

Monthly

Check motor idle current.
Check RTD for temp. and temp. spread.
Check vibration.
Grease motor bearings. (LiEP2)

Quarterly

Clean and flush circulating oil lubrication system and refill with clean oil and change filters. (Paradene X1000) (Purolator #6666063,25 micron filter element).
Grease coupling and jacks lift bearings. (LiEP2)
Rebuild and hardface spider ends, hammers, and liners, where required.
Check coupling alignment.

CONTINUED

TABLE 9. (Continued)

Semiannually

Clean and flush all bearing housing and change filter element. (Paradene X1000) (Purolator #6666063).
Remove all hammers and pins. Check rotor for balance. Check rotor shaft for runout using a dial indicator.
Clean and flush hydraulic system. Refill with new oil. (Paradene 430) (#5610 Char Lyn filter).
Replace all side liners and discharge chute liners that are extremely worn.
Grease motors. (LiEP2)
Check and megger motor.
Check heaters.
Check RDT monitor, clean when necessary.
Check bearing condition.
Check vibration switches.
Check close mechanical interlock for quadrant.
Check quadrant hold and pin puller motors.
Check quadrant hold switch interlock.
Check lubricating oil pressure switch, bearing temperature thermisters, temperature monitor and shutdown.
Check motor starter cabinet - clean if necessary.
Check control panel conveyor shutdown.
Check CO_5 relay, GFR and cabinet heater.
Check cooling water control switch.
Check all alarms.
Check motor control circuits and contactors for cleanliness.

Annually

High pot motors.
Check calibration of CO_5 and 80 relays.
Check operation of watt loss relay.

Shredder Discharge Conveyors

The refuse discharged from each shredder falls vertically into an inclined vibrating pan (called the shredder discharge conveyor) which in turn transfers the waste to a rubber belt conveyor (called the shredder refuse collection conveyor, which is discussed later).

Description

Each of the two discharge conveyors is a Stevens-Adamson, power-imbalanced, vibrating (Vibra Coil) pan assembly approximately 2 m (6 ft) wide, 4.5 m (15 ft) long, and 0.3 m (1 ft) deep. The pan portion of the conveyor is made of abrasion-resistant steel with extra heavy steel-plate pan construction. The pan is mounted on the structural steel supports of a heavy structural steel base for standard rigid floor mounting. Centered directly below the shredder refuse outlet, the steel base was initially bolted to the concrete floor. The pan is installed at a 5° decline. A positive mechanical eccentric drive vibrates heavy-duty, low-stress, power-regenerating steel coil springs and, in turn, the pan. Heavy-duty stabilizer bars mounted in rubber bushings guide the pan through its linear oscillation.

To relieve any explosion pressure within the shredder, the pan is equipped with a horizontal duct that vents to atmosphere. A screen and a deflector plate in the duct prevent the discharge of any high velocity projectiles which could cause personal injury.

Operating Experience

When initially anchored directly to the concrete floor, the pan assembly transmitted such extreme vibration to the floor and then through the entire shredder building that some of the sensitive instruments in the control room about 12 m (40 ft) from the shredder building malfunctioned. To effectively reduce this vibration transmission required installing isolation springs between the floor and the structural steel support. Consequently, concrete inertia blocks were installed on the base of the pan for the resistance needed to vibrate the pan with the eccentric drive operation (Figure 22).

To prevent cutting or tearing the rubber belt conveyor as the refuse fell from the pan conveyor, the discharge chute of the conveyor was originally equipped with deflection plates installed 61 cm (2 ft) apart and at an approximate 60° slope. After the plates had frequently plugged the chute with consequent waste backup on the pan and into the shredder, they were removed. The plates proved to be unnecessary since the belts have remained intact after the plate removal.

During extremely cold weather, waste not cleaned off the pan conveyor before the end of a shredder shift caused severe jamming during the next shift. When the shredder was restarted with the retained waste frozen to the pan conveyor, new waste could not pass down the conveyor and accumulated back up into the shredder where the hammers compacted and forced it through the grate causing severe jamming.

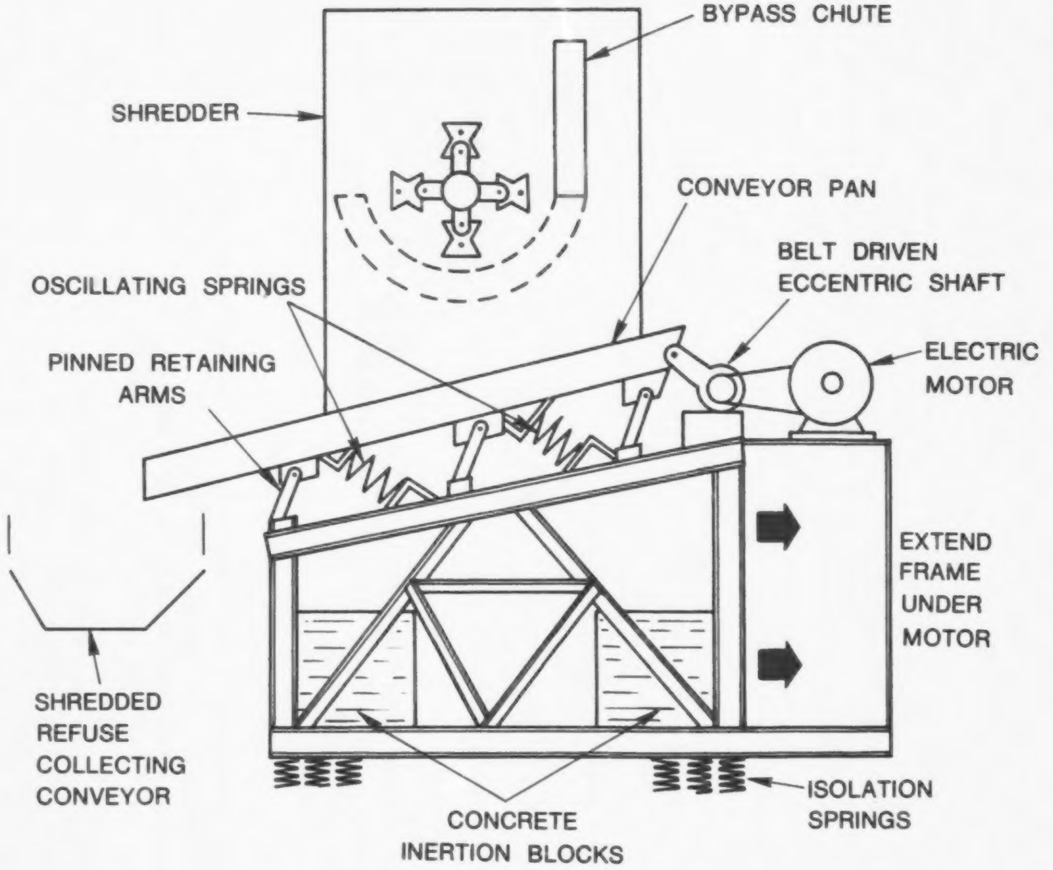

BYPASS CHUTE
SHREDDER
CONVEYOR PAN
BELT DRIVEN ECCENTRIC SHAFT
OSCILLATING SPRINGS
ELECTRIC MOTOR
PINNED RETAINING ARMS
EXTEND FRAME UNDER MOTOR
SHREDDED REFUSE COLLECTING CONVEYOR
ISOLATION SPRINGS
CONCRETE INERTION BLOCKS

Figure 22. Shredder discharge conveyor.

The pan conveyor was designed to transfer from the shredder to the rubber belt conveyor 283 cu. m (16,000 ft^3) per hour of refuse shredded to a bulk density of 240 kg/m^3 (15 lb/ft^3) for an equivalent mass flow of 68,000 kg per hour (150,000 lb/hr). However, since the design bulk density is much greater than the measured bulk density of 50 kg/m^3 (3 lb/ft^3), the actual pan conveyor capacity is far below its design capacity. Although the pan conveyor has jammed when the bulk densities are extremely low, 20 kg/m^3 (1.3 lb/ft^3), it has performed satisfactorily when the bulk densities are about 50 kg/m^3 (3 lb/ft^3). Because of the reduced capacity of the entire shredder system, the limiting effect of the pan conveyor on the overall plant operation cannot be determined.

Jamming caused by variations in the waste density are especially critical below the shredder discharge because of the small 46 cm (18 in.) clearance between the vibrating pan and the shredder outlet. Since the shredder support frame is directly above the pan, such jamming could be minimized by either lowering the pan for more clearance or increasing its incline for better flow. A preliminary study, however, indicated that the improved refuse flow would not justify these costly modifications.

When waste jams below the shredder discharge, its removal requires from 8 to 24 hours because of the difficulty in gaining access to the constricted area and the further compacting of the refuse by the shredder. To minimize these jams, the plant personnel continue the pan conveyor vibration several minutes after each shredder shutdown and, as discussed above, no longer use the truck bays which dump directly onto the storage pit conveyors. Consequently, the bulldozers scatter and compact all refuse, particularly concentrations of such low-density material as paper and hay, so that the refuse ultimately fed to the shredders is more homogeneous and has a greater average density.

Rubber skirts installed at the base of the shredder have minimized, but not completely eliminated, escaping dust and particles which scatter throughout the shredder building.

Maintenance

The pan conveyors have required the normal amount of maintenance expected with such vibrating equipment. However, the isolation springs and their retaining bolts have broken frequently; heavier duty springs or an alternative spring material could be substituted to minimize these failures.

Because of the severe service, overloading, and jamming, several links on one of the pan conveyors have failed. In addition, one of the eccentric drive shafts for the pan conveyor had bent excessively. Although the drive shaft is one of the most carefully engineered components, this particular shaft probably failed because of jamming where the waste compacted against the shredder support beams so restricted the conveyor motion that the shafts and links push against an unyielding mass.

The preventive maintenance schedule for these units is detailed in Table 10.

TABLE 10. VIBRATING PAN CONVEYOR PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check for abnormal noise or vibration.
Make visual inspection for loose or missing bolts, linkages, or broken spring units.
Lubricate pillow block bearings, connecting rods, and drive shaft bearings. (LiEP2)

Quarterly

Check belts for tension and wear.

Semiannually

Grease motor bearings. (LiEP2)
Check motor, alarms, and interlocks.

Annually

Megger motor.

STORAGE AND RECOVERY MODULE

As represented by the shaded areas in Figure 23, the storage and recovery module was designed for a storage capacity of 1800 Mg (2000 tons) of shredded refuse which would normally suffice for the continuous recovery of shredded refuse at a controlled rate so that the thermal processing module could continue operating during the night, weekends, and holidays when the receiving and size reduction modules are not operating. The module was also designed to remove large pieces of magnetic metal from the shredded refuse stream.

The first of the functionally integrated components in this module are two shredded refuse conveyors aligned in series: a horizontal conveyor which collects the refuse from the shredder discharge conveyor and then an inclined conveyor which, upon receiving the shredded refuse from the collection conveyor, elevates the waste to a transfer tower. Within the tower, the shredded refuse is discharged near a magnetic drum separator.

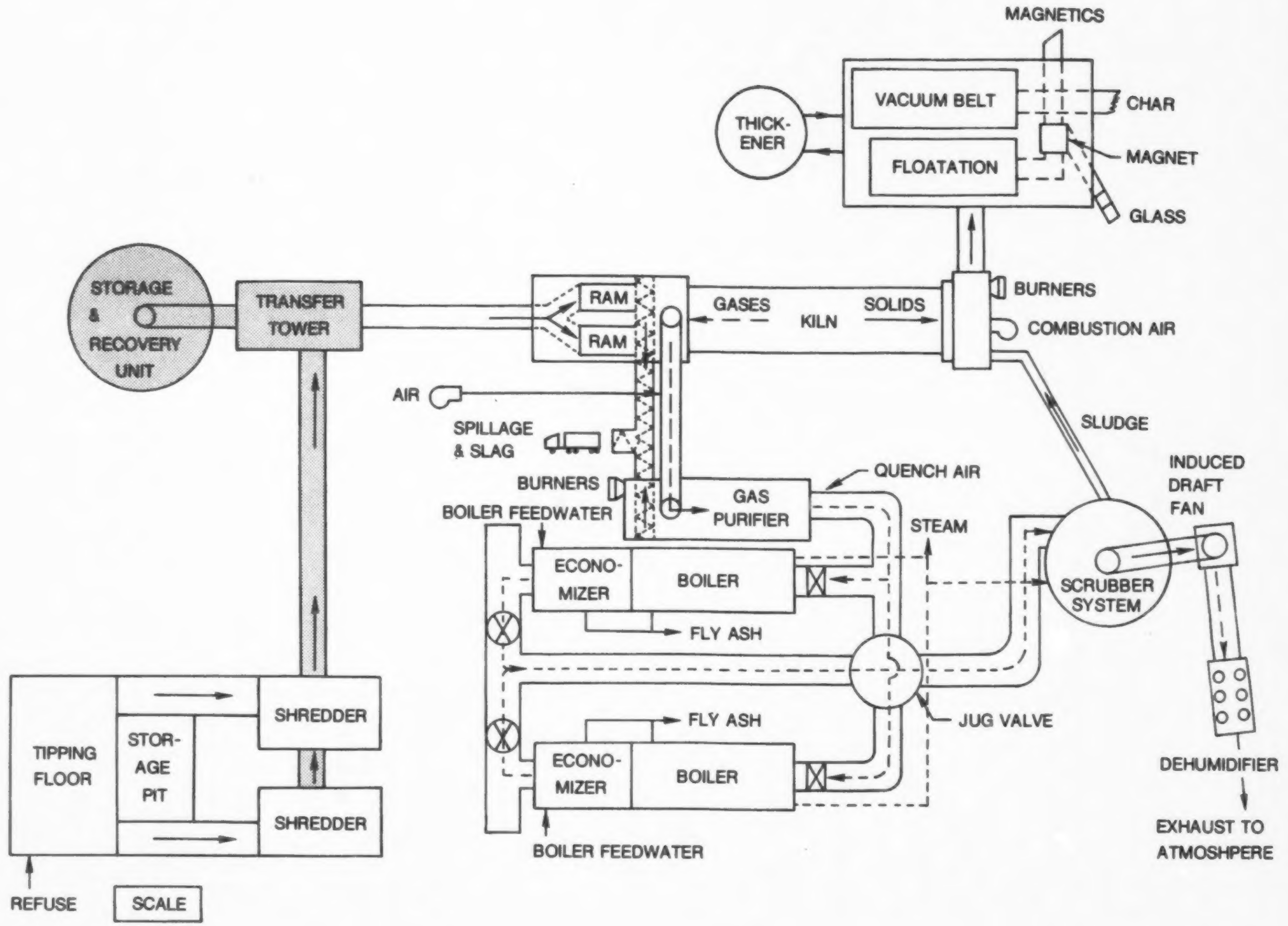

MAGNETICS
THICK-ENER
VACUUM BELT
FLOATATION
CHAR
MAGNET
GLASS
STORAGE & RECOVERY UNIT
TRANSFER TOWER
RAM
RAM
GASES
KILN
SOLIDS
BURNERS
COMBUSTION AIR
AIR
SPILLAGE & SLAG
SLUDGE
BURNERS
QUENCH AIR
INDUCED DRAFT FAN
BOILER FEEDWATER
GAS PURIFIER
STEAM
ECONO-MIZER
BOILER
SCRUBBER SYSTEM
FLY ASH
JUG VALVE
FLY ASH
ECONO-MIZER
BOILER
DEHUMIDIFIER
TIPPING FLOOR
STOR-AGE PIT
SHREDDER
SHREDDER
BOILER FEEDWATER
EXHAUST TO ATMOSHPERE
REFUSE
SCALE

Figure 23. Storage and recovery module (shaded area).

While it was operative, the magnetic drum separator removed from the refuse stream most of the magnetic metals and deposited them on a vibrating screen conveyor which discharged metal pieces over 15 cm (6 in.) for truck or hopper removal and returned the rest to the shredded refuse stream.

In the ductwork below the magnetic metal separating system are two flop gates which operate in synchrony to direct the shredded refuse flow onto the shredded refuse transfer conveyor for refuse transport to the storage and recovery unit or to a bypass chute for direct refuse delivery to the kiln feed conveyor in the thermal processing module. As discussed below, the storage and recovery unit has been discontinued and only the bypass chute is used.

When the silo storage and recovery unit was operating, the shredded refuse transfer conveyor transferred the waste to a spreader at the top of the silo for the even distribution of the dumped refuse on the silo floor. Then, as detailed in the following subsections, the stored refuse was recovered for its discharge at a controlled rate onto the kiln feed conveyor.

The magnetic drum separator was discontinued for the threefold reason that the magnetic accumulations in the drum impeded the drum effectiveness, the vibrating screen conveyor plugged excessively, and, as discussed in the section for the thermal processing module, the retention of the larger metal pieces with their high densities facilitated the sinking and removal of the kiln residue in the residue quench tank.

The normal usage of the storage and recovery unit terminated when the wearout of the silo concrete floor precluded using most of the refuse recovery (retrieval) equipment. Then after a short period of limited usage, various operational difficulties prompted the discontinuance of the unit entirely. Therefore, the module is currently used only to transport the shredded refuse to the thermal processing module.

Shredded Refuse Conveyors

Except for their function, length, and powering, the three shredder refuse conveyors--collection, elevation, and transfer--are basically the same. The refuse discharged from the shredder falls vertically onto the collection conveyor which in turn discharges the shredded refuse to also fall vertically onto the elevating conveyor. The latter conveyor then transports the waste up to the top of the transfer tower, shown in Figure 24. There, as designed, the waste would pass near the magnetic drum separator for iron removal and then the remaining refuse would be conveyed either to the storage and recovery unit by the transfer conveyor or directly to the kiln feed conveyor through a bypass chute.

Description

Manufactured by the Bulk Systems Division of the Jervis B. Webb Co., each of the shredded refuse conveyors is a rubber belt conveyor 1.9 m (6 ft) wide with equal-length, steel-roll, troughing idlers set at 35°. The

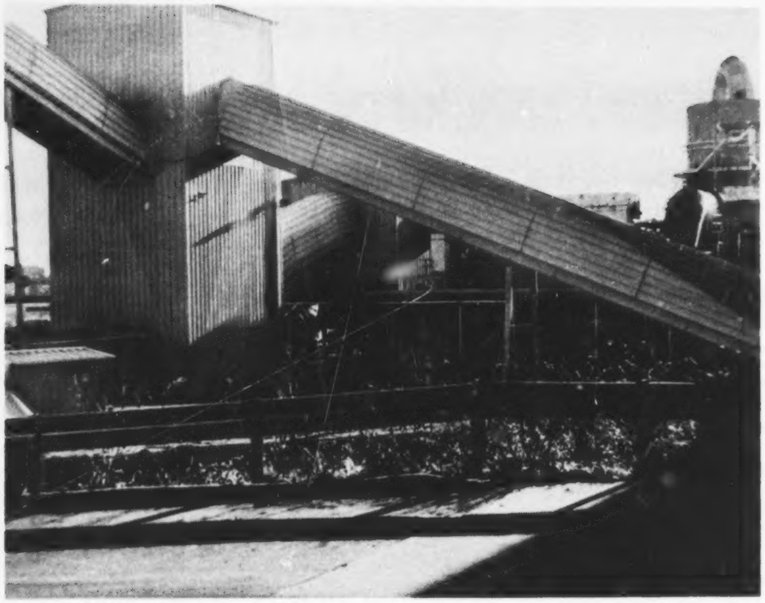


Figure 24. Transfer tower.

troughing idlers are on 1.2 m (4 ft) centers except in the loading area where they are on 0.6 m (2 ft) centers. The trough transition idlers at each end of the conveyors consist of 20° idler rollers, and the return idlers are a self-cleaning disk type. The head pulley on each conveyor is a crown-faced, welded-steel, conveyor pulley with 1-cm (0.5-in.) thick, herring bone groved, rubber lagging, and the take-up tail pulley is a bare-crown-faced steel pulley. Two knife-edge, rubber counter-weighed belt wipers are installed in series with the head pulley of each conveyor.

At each load transition point, the conveyors are enclosed by a hood which is attached to a dust collection system and which was originally fitted with rubber skirts. Further, each conveyor is enclosed entirely by a weatherproofed gallery. In addition to weather protection, the gallery was designed to contain waste spillage.

The collection conveyor is a 50-m (165-ft) long horizontal belt driven at 88 m (290 ft) minute by a 7.5-hp electric motor. This conveyor runs beneath the shredder discharge conveyors and perpendicular to its flow.

The elevation conveyor is a 50-m (165-ft) long, 20° inclined rubber belt driven at 91 m (300 ft) per minute by a 20-hp electric motor.

The transfer conveyor is 37.4-m (123-ft) long, 20° inclined rubber belt driven at 94 m (310 ft) per minute by a 7.5-hp electric motor.

The progressively higher conveyor speeds, 88 m (290 ft), 91 m (300 ft), and 94 m (310 ft) per minute, were intended to ensure that the waste dumped at the transfer points would be carried away without any retained on a conveyor return run.

Operating Experience

The three shredded refuse conveyors were designed to operate 16 hours per day, 6 days per week. However, because of the suspension of the storage and recovery unit, only the collection and elevating conveyors are being run. Further, because of the continuous operation of the size reduction module, the latter two conveyors are being operated 24 hours per day, 6 days per week.

On the basis of bulk densities between 160 and 400 kg/m^3 (10-25 lb/ft^3) the conveyors were originally for a capacity of 182 Mg (200 tons) per hour that would handle the refuse of three shredders. However, since the measured bulk densities have ranged from 18 to 80 kg/m^3 (1-5 lb/ft^3) these conveyors would likely limit the waste flow if the existing two shredders were operated at their design capacity. Moreover, if the third shredders were installed, the entire shredded refuse conveyor system would have to be redesigned. However, in view of the low shredder capacity, the conveyors thus far have generally not had excessive lateral overflows due to volume overloading. Consequently, whereas the conveyor system was overdesigned, it should be capable of conducting the currently normal waste flow because of the reduced shredder operation.

The three shredder refuse conveyors are so interlocked that the shutdown of one stops the preceding conveyors to prevent waste from piling up. Similarly, the elevating conveyor was interlocked with the magnetic drum separator, and the transfer conveyor was interlocked with both a high-level alarm and the discharge conveyor in the storage and recovery unit. When the elevating conveyor was interlocked with the transfer conveyor, it could continue running, regardless of the transfer conveyor operation, whenever the waste bypass gate was open.

The refuse on the 20° incline of the elevating and transfer conveyors have tended to slip on the smooth-faced belts or remain stationary with the belt movement whenever the gravitational force exceeds the adhesion force. Except for solid waste with an unfrozen moisture content between 10 and 40 percent, the refuse generally has insufficient adhesive force when it is dry, frozen, or light with bulk densities such as those for paper and similar materials. The resultant waste slippage has contributed to the jamming, plugging, and overloading of the conveyor belts and transfer duct work.

Since the too-steep 20° incline cannot be reduced, the slippage could be controlled only by roughing the belts or installing belt cleats. However, such modifications have not been implemented because they would hamper the effectiveness of the belt wipers and intensify the cleaning maintenance.

Most of the operational problems with the shredded refuse conveyors have dealt with the control of waste spillage and dust, particularly at the transfer points (Figure 25). These problems have been aggrevated by the need

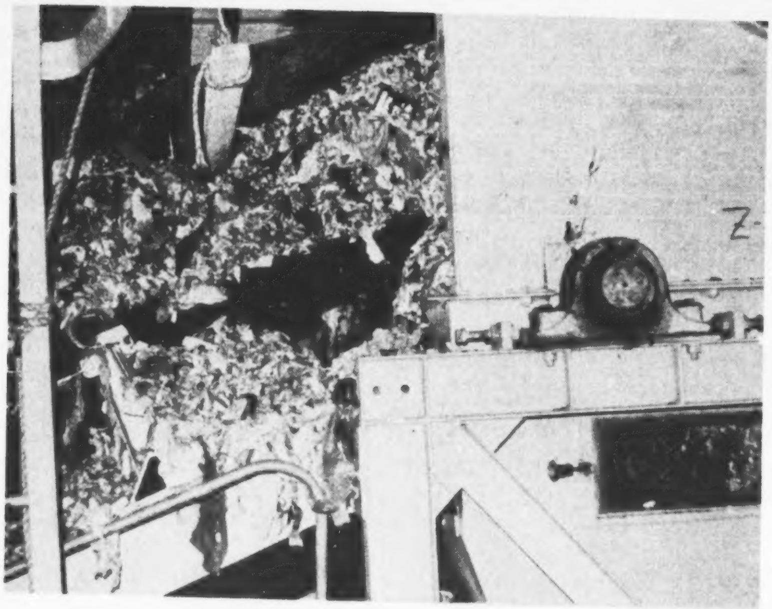


Figure 25. Refuse jam at the elevating conveyor discharge.

to remove the rubber skirts from the transfer hoods, as discussed below, and the current ineffectiveness of the belt wipers on each conveyor. These wipers have so worn that they no longer clean the belts and allow waste to spill on the return runs of the conveyor belts.

The rubber skirts attached to the conveyor hoods at the transfer points were designed to complement the dust collection system in containing the large amount of dust lofted from the vertically falling waste. However, these skirts had to be removed because their excessive drag on top of the belt waste restricted the belt movement and caused the backup of light-density materials.

To partially solve the waste spillage and dust problem, the pile height on the conveyors was reduced by increasing the belt speed. This required installing larger motors (5 hp vs. 2 hp) on the conveyor. However, because of the increased oil viscosity in the gears, these motors are difficult to start in cold weather. In addition, the increased motor torque requirements at start-up, because of the faster belt velocity, have frequently caused motor overloading and shutdown.

Since the shredded refuse conveyors form a single-line link with no redundancy, any conveyor failure will shut down the waste preparation and consequently the entire plant processing.

Maintenance

Except for the waste spillage and dust control, the shredded refuse conveyors have generally required only routine maintenance to keep the conveyors lubricated and aligned. Jammings at the transfer points, particularly those due to waste slippage on the inclined conveyors, have required 8 to 16 hours to clean. Also, several lubricating fittings installed on the conveyor rollers have had to be replaced because of their breaking off. In addition, a set of pillow block bearings and a tail pulley have also had to be replaced because of failures likely due to highly abrasive glassy grit. The preventive maintenance schedule for these conveyors is shown in Table 11.

Magnetic Drum Separator System

The magnetic drum separator was designed to extract magnetic materials, particularly those which entered the refuse stream through the shredder oversized chute, from the discharge of the shredded refuse elevating conveyor and then deposit the extracted materials onto the vibrating screen conveyor.

The vibrating screen conveyor was designed to divide the metallic materials deposited by the magnetic drum separator into two sizes: (1) materials larger than 15 cm to be discharged into a truck or hopper for metal recycling or disposal, and (2) materials smaller than 15 cm to be returned to the shredded refuse stream for conveyance to either the storage and recovery unit or to the bypass chutes.

Description

The magnetic drum separator consists of a 1.8-m (6-ft) diameter hollow drum rotating counterclockwise at approximately 60 rpm with a stationary magnet inside. The separator is suspended 0.5 to 0.6 m (20 to 24 in.) above the head pulley of the shredded refuse elevating conveyor. As the waste is discharged from the elevating conveyor to fall freely, the magnetic metals are drawn and adhere to the drum at the 7 o'clock position while the remaining refuse falls to the bypass chute flop gate below. As the drum rotates, magnetic materials adhere to the drum in the magnetic field area and then fall off onto the vibrating screen conveyor at the 4 o'clock position where the magnetic field is no longer effective (Figure 26). Steel-plate vanes 0.6 m (2 ft) wide and 10 cm (4 in.) high along the drum circumference prevent slipping materials from remaining in the magnetic field.

The separator is interlocked with the vibrating screen conveyor and the sprinkler system so that it cannot operate unless the conveyor is running to prevent depositing material on the inoperative conveyor, and the sprinkler system is turned on to prevent the transfer of burning material.

Manufactured by Linkbelt-FMC, the vibrating screen conveyor is a floor-mounted, single-decked, vibrating scalper screen with a 1.2-m (4-ft) by 2.4-m (8-ft) feed plate and a 1.2-m (4-ft) by 1.8-m (6-ft) screen area yielding a total area of 1.2 m (4 ft) by 4.2 m (14 ft). The frame is a steel construction, and the feed box has an abrasion-resistant renewable liner. The screen openings were originally 15 cm (6 in.) square.

TABLE 11. SHREDDED REFUSE CONVEYOR PREVENTIVE MAINTENANCE SCHEDULE

Weekly

Check idlers, belt alignment, and neatness at tail pulley.
Check oil level in reducers. (Paradene 475)

Monthly

Check take ups for worn parts; idlers and cables to counterweight; safety cables and cable switch boxes, connections, and especially belt wipers.
Operate inspection gates.
Remove and clean breather cap on gear reducer.
Lubrication:
    Head and tail pulleys, idlers and pillow blocks, and sprockets. (LiEP2)
    Take up cable pulleys. (Paradene 475)

Quarterly

Check V-belts.
Change gear reducer oil. (Paradene 475)

Semiannually

Grease motors. (LiEP2)
Check motor, alarms, and interlocks.
Inspect and lubricate pull cord switch.

Annually

Megger motor.

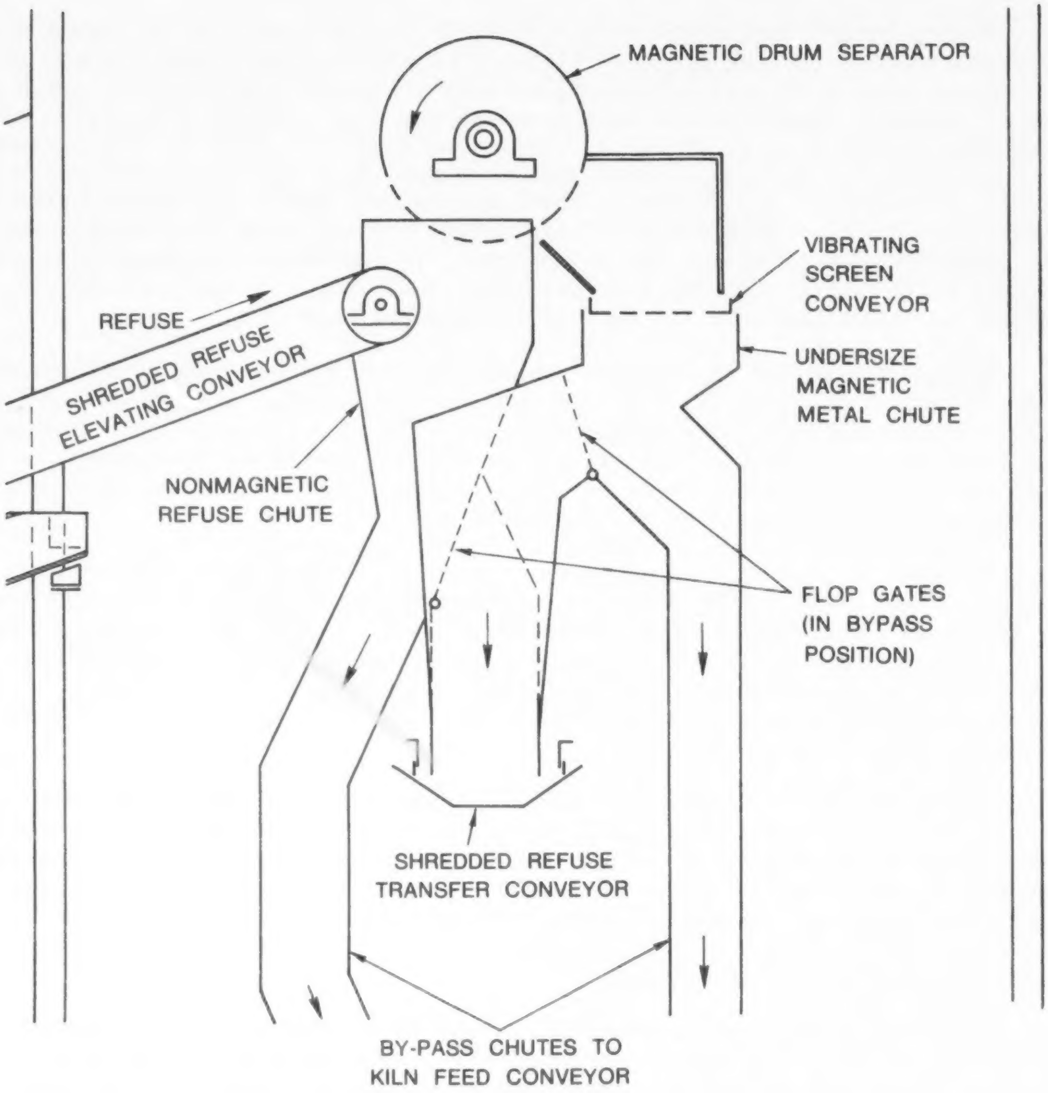

MAGNETIC DRUM SEPARATOR
VIBRATING SCREEN CONVEYOR
REFUSE
SHREDDED REFUSE ELEVATING CONVEYOR
UNDERSIZE MAGNETIC METAL CHUTE
NONMAGNETIC REFUSE CHUTE
FLOP GATES (IN BYPASS POSITION)
SHREDDED REFUSE TRANSFER CONVEYOR
BY-PASS CHUTES TO KILN FEED CONVEYOR

Figure 26. Magnetic drum separator system and bypass chutes.

Operating Experience

The separator was designed to be operated whenever the shredders were running, that is, 16 hours per day, 6 days per week. However, because of the operational problems, discussed below, and the poor quality of the recovered metals, the separator operation was suspended.

With a burden feed depth of 0.4 m (16 in.), the separator was designed to extract up to 12.7 Mg per hour (14 tph) of metals from a waste stream of 159 Mg per hour (175 tph). However, with these design requirements, waste on top of magnetic materials was also drawn to the drum surface and carried over into the recovered metal stream. This burden depth resulted in a 68 percent recovery rate and the waste carryover decreased the metal purity to approximately 88 percent. Such impurity requires that the metal stream be further refined before the recovered metal can become commercially acceptable. While the magnetic drum separator was operational, the conveyor, as designed, was capable of matching the separator capacity of 12.7 Mg per hour (14 tph) during the scheduled 16 hours per day, 6 days per week.

At the drum rotational speed of about 60 rpm, tin cans and other small ferrous materials generally flew off the drum rather than falling off the drum and onto the vibrating screen conveyor. To minimize this condition and the resultant cleanup requirement, the drum was enclosed with a screen. Consequently, after a steady-state condition developed within the enclosure, all such materials fell onto the conveyor.

In addition, because of the magnetic strength required for operation with a 0.4-m (16-in.) burden depth, numerous metals drawn to the drum surface became so magnetized that they stayed fast to the drum in such accumulations that they retarded the effectiveness of the magnetic field and intensified the cleaning maintenance. Moreover, steel components in the separator structure became similarly magnetized to attract and retain excessive amounts of metallic materials.

To prevent materials discharged by the magnetic drum separator from accumulating on the sharp edge of the screen formed by its side board required removing this board and any protrusions into the discharge path. In addition, because of the insufficient clearance between the screen and the discharge duct work when the conveyor vibrated, several inches of plate had to be removed from the ducts. The plate removal in turn required a rubber flap installation to minimize leakage.

When rags, wire, and chain had continually plugged the screen openings, the 15-cm (6-in.) squares were replaced with 15-cm (6-in.) wide slots extending the entire screen length. While the slots were intended to allow the materials to slide through the inclined screen as the conveyor vibrated, the materials continued to plug because of their draping over the screen-length bars.

For a short period of time, a steel plate was placed over the screen openings on the vibrating conveyor to direct all of the recovered magnetic metal stream to a truck through the oversize chute. This was attempted because ferrous materials with alloy coatings, such as tin cans, have a higher market value when recovered before thermal processing (which vaporizes the alloys). The low purity of the recovered metal, discussed previously, and the consequent problem of floating residue in the residue quench tank, discussed later, have resulted in the suspension of the magnetic drum separator system operation.

Future designs of magnetic drum separators should consider (1) reducing the burden depth at the separator inlet so that with a smaller-strength magnet (a) refuse would not be carried along with metallic materials to pollute the metal stream and (b) materials would not be so magnetized that they would adhere permanently to the drum surface, (2) establishing an optimum drum rotational speed such that metal temporarily attaching to the drum surface would fall off onto the vibrating screen conveyor rather than fly away from the drum, and (3) constructing the drum of nonmagnetic materials.

Since elongated materials such as wires and textiles are apt to bridge and plug a screen, vibrating screen conveyors of the type described above should be applied only when the appropriate material size is carefully controlled. The basic parameters of such conveyors should be further researched before applying existing designs or developing new ones.

Maintenance

Except for cleaning, the separator required minor preventive maintenance (Table 12) during its limited operation. However, before the separator could become operative during its initial start-up, a factory representative had to adjust the separator mechanism.

The vibrating screen conveyor had required continual checking and much maintenance because of excessive drive belt wear and the difficulty in keeping the belts on the sheaves. Since the drive motor is stationary while the driven unit is on the vibrating pan, the varying drive belt tension causes the belts to jump off the sheaves and, of course, sustain severe wear. The preventive maintenance schedule for the vibrating screen conveyor includes (1) semi-annual check of the motor bearings, alarm, and interlock and lubrication of the bearings (LiEP2), and (2) annually megger the motor.

Storage and Recovery Bypass Chutes

The unit bypass chutes make up one of the two routes for the continuance of the refuse and undersize magnetic metal streams after being discharged from the shredded refuse and the vibrating screen conveyors, respectively. The other route is to the storage and recovery unit. The following description covers the means of directing the refuse flow to one route or the other as well as the bypass chutes themselves.

TABLE 12. MAGNETIC DRUM SEPARATOR PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check reducer and chain.
Check oil level in gearmotor. (EP8)
Check bearing and chain lubrication. (Paradene 430)

Quarterly

Change gearmotor oil. (EP8)

Semiannually

Change bearing and chain oil. (Paradene 430)
Grease motor. (LiEP2)
Check output voltage and amperage to magnet for all three phases.
Lubricate off/on switch for magnet.
Check drum motor, alarm, and interlock.

Annually

Megger motor.

Description

As designed, the refuse discharged from the shredded refuse elevating conveyor and the undersize magnetic metals discharged from the vibrating screen conveyor were to be conducted to either of two routes by operating two pneumatically controlled steel flop gates. The two flop gates are installed at the junctions of the two sets of inverted Y-shaped duct work below the elevating conveyor and the vibrating screen. One branch of the Y in both sets of duct work discharges onto the shredded refuse transfer conveyor that feeds to the storage and recovery unit while the other branch becomes the storage and recovery bypass chutes which feed to the kiln feed conveyor (Figure 26).

Again, as designed, the refuse was to be directed to the silo system bypass chutes only when the silo system was inoperative or filled as determined by the chief operator in the control room. One switch controls both gates so that all refuse flows to the same point. The bypass chutes are 30-inch-square, steel-plated ducts designed to handle refuse of average density.

Operating Experience

Refuse has frequently jammed in the ductwork because of (1) refuse with low density, wires, or textiles, (2) the tendency for the gate to not shut completely when the grate is being closed with refuse passing through the ductwork, and (3) refuse slippage on the kiln feed conveyor. Consequently, accesses with sliding doors were installed to facilitate the jam removals. Moreover, although the gates were trimmed for adequate clearance (since they were originally too large to allow for free movement), dust and grit entering the pneumatic system near the gates have caused the gates to jam or shift when in the bypass position. Such gate malfunctions have contributed further to the refuse jamming in the ductwork. As previously suggested, a light indicating the gate position should be installed to inform the chief operator in the control room of the gate status.

The refuse fed directly to the thermal processing module through the bypass chutes cannot be weighed since the routing of the chutes is beyond the belt scale on this conveyor and the scale, according to its manufacturers, should not be moved nearer to the conveyor discharge end. In addition, bypassing the scale decreases the efficiency of the automatic process control in the thermal processing system because the control in linking directly to the belt scale depends on its weight measurement. These deficiencies could be remedied by installing a second belt scale on the shredded refuse elevating conveyor.

A baffle and rubber skirt were added to the bypass chute discharge above the kiln feed conveyor to control the falling refuse. While this installation minimized the waste spillage, it had a negligible effect in containing the dust.

Although the pybass chute duct work is generally satisfactory, future designs should include the following to minimize jamming and the consequent cleaning maintenance: larger ducts, smoother duct contours, and relief areas in the ducts opposite the flop gates to prevent waste from accumulating between the gate edge and the duct work wall when the gates are opened with waste flowing in the duct work.

Maintenance

The bypass duct work and gates have required little maintenance other than routine cleaning of the solenoid valves to operate the flop gates. The operation of the solenoid valves, the air supply pressure, and the condition of the pneumatic cylinders should be checked annually as a preventive maintenance measure.

Stored Material Spreader

As discussed in the next section, the operation of the storage and recovery unit has been suspended indefinitely. While the system was operational the shredded refuse conveyor would discharge the waste at the top and center of the silo shell. Then the refuse would fall onto a floor-centered cone whose slope would cause the waste to slide toward the silo periphery.

The stored material spreader, installed directly below the discharge area and on the silo vertical centerline, was designed to further distribute the waste to facilitate both the storage and the subsequent recovery of the refuse.

Description

The spreader was designed to distribute up to 136 Mg per hour (150 tph) of refuse with a bulk density between 160 and 400 kg m^3 (10 to 25 lb/ft^3). In its original configuration, the spreader was a two-arm rotary plow which made one rotation a minute. As the waste pile rose to above three-fourths of the silo height, the rotary plow would force the uppermost waste layers further toward the silo periphery. However, as explained below, the spreader was modified to incorporate a rotary distribution chute. With the two-arm plow left intact but not used and the spreader assembly still geared to make one revolution a minute on the silo vertical centerline, the chute was intended to make the waste distribution over the floor more uniform. The chute assembly rotates on wheels with a discharge chute projecting oblique (Figure 27).

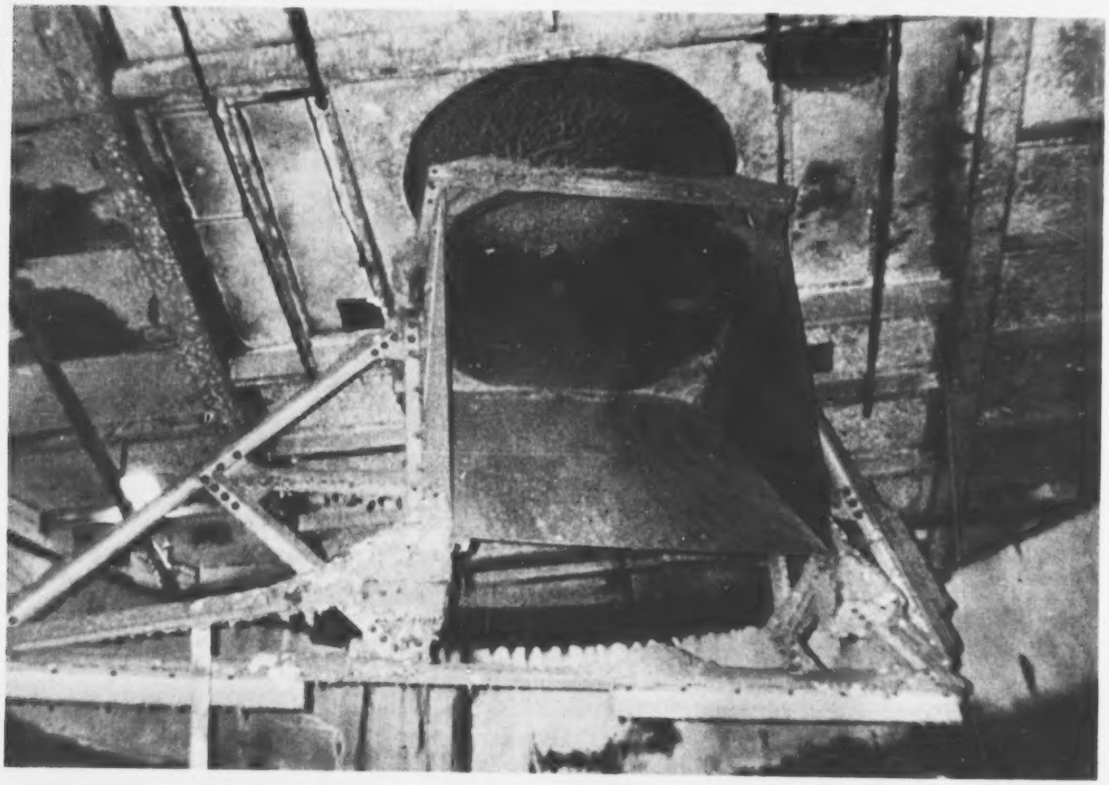


Figure 27. Stored material spreader.

Operating Experience

Throughout the spreader operation with both the two-arm rotary plow and the rotary distribution chute, the lower-than-designed bulk density of the waste distribution from the shredders had no appreciable effect on the spreader performance.

While the two-arm rotary plow was effective in sweeping away the upper layers of the refuse piles, it could not distribute the waste with the desired uniformity. Consequently, rather than allowing the refuse to freely fall and pile up, the rotary distribution chute was introduced to ensure a uniform distribution.

During the initial rotary chute operation, the chute rotation was hampered because the load concentration at the chute discharge imbalanced the weight distribution on the wheels. Therefore, a three-point-support truck wheel system was installed to ensure an even load on all wheels. In addition, sealed bearings were installed in the chute assembly to minimize wear due to pulverized glass. After these modifications, the rotary chute had no downtime and required only the preventive maintenance detailed in Table 13.

TABLE 13. STORED MATERIAL SPREADER PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check condition of drive wheel, drive chain, gear reducer, and carrying rollers.
Check oil level in gear reducer. (EP8)
Lubricate drive chain. (Paradene 430)

Semiannually

Change, reduce oil. (EP8)
Oil chain. (Paradene 430)
Grease cam followers and motor. (LiEP2)

Storage and Recovery Unit

The storage and recovery unit was designed to provide a 2-day refuse supply that would permit the thermal processing system to continue operation over the weekend when refuse was not delivered to the plant. However, when the wear-out of the silo floor precluded normal waste recovery operations, the silo was used only for emergencies such as when the bypass chutes jammed. Then after a short period of such usage, the entire silo system operation was indefinitely suspended.

As discussed in the previous section for the stored material spreader, the refuse initially dumped into the silo would fall about the floor-centered cone and the successive dumpings would progressively more toward the silo periphery. Therefore, the last deposits with their greater circumferential distributions and floor area extent would be the first subject to the floor removal operations. Consequently, the waste would generally be removed in the reverse order of dumping or in a first-in last-out sequence.

Description

On the basis of a bulk density of 400 kg per cu m (25 lb/ft^3), the storage and recovery unit was designed for a waste input of 181 Mg per hour (200 tph), a storage capacity of 1815 Mg (2000 tons), and a waste output of 38 Mg per hour (42 tph).

Manufactured by Atlas, the silo is a steel-plated conical shell 18 m (60 ft) high, with a 24 m (80 ft) diameter (which protects the refuse from wind and precipitation) mounted above a concrete floor. As shown in the cutaway view in Figure 28, the major silo components are (1) a floor-centered hollow cone, (2) three sweep bucket chains, (3) a bucket chain-drive system (pullering), and (4) a discharge drag chain conveyor which extends in a trough across the silo diameter and beneath the cone.

The floor-centered cone was designed to distribute the falling refuse over the floor area and to serve as a pivot for the trailing end of the bucket chain sweeps. Constructed of 0.6-cm (0.25-in.) steel plate and anchored to the floor, the original cone has a 2.4-m (8-ft) base diameter and a 3.6-m (12-ft) height.

The sweep bucket chains were designed to pull the floor-level refuse from the pile and then push it and successively falling layers of refuse to the discharge conveyor. Each chain consists of a series of rectangularly shaped buckets each connected to its adjacent buckets by solid steel pins.

As discussed below, the original four chains with 10 buckets each were replaced by three chains with 20 buckets each. With the front side and bottom open, each bucket is fabricated of 1-cm (.375-in.) thick steel plates which are mounted on 2.5-cm (1-in.) thick wear shoes. Each bucket (Figure 29) is 46 cm (18 in.) wide, 81 cm (32 in.) long, and 40 cm (16 in.) high for a volume of 0.15 m^3 (5 ft^3). The loading end of each chain was attached to the chain-drive system which pulled the chains in a rotary sweep around the floor while the trailing free-moving end tended to pivot about the floor centered cone.

The chain-drive system consists of a motor-driven, wheel-mounted ring. The ring ran between guide rails along the floor periphery and was driven by two variable-speed D.C., motors, a 70 hp lead motor and a 30 hp support motor.

Extending across the silo diameter and beneath the floor-centered cone, the discharge drag chain conveyor runs in a trough constructed of abrasion-resistant steel below the floor level. A tunnel beneath the trough provides

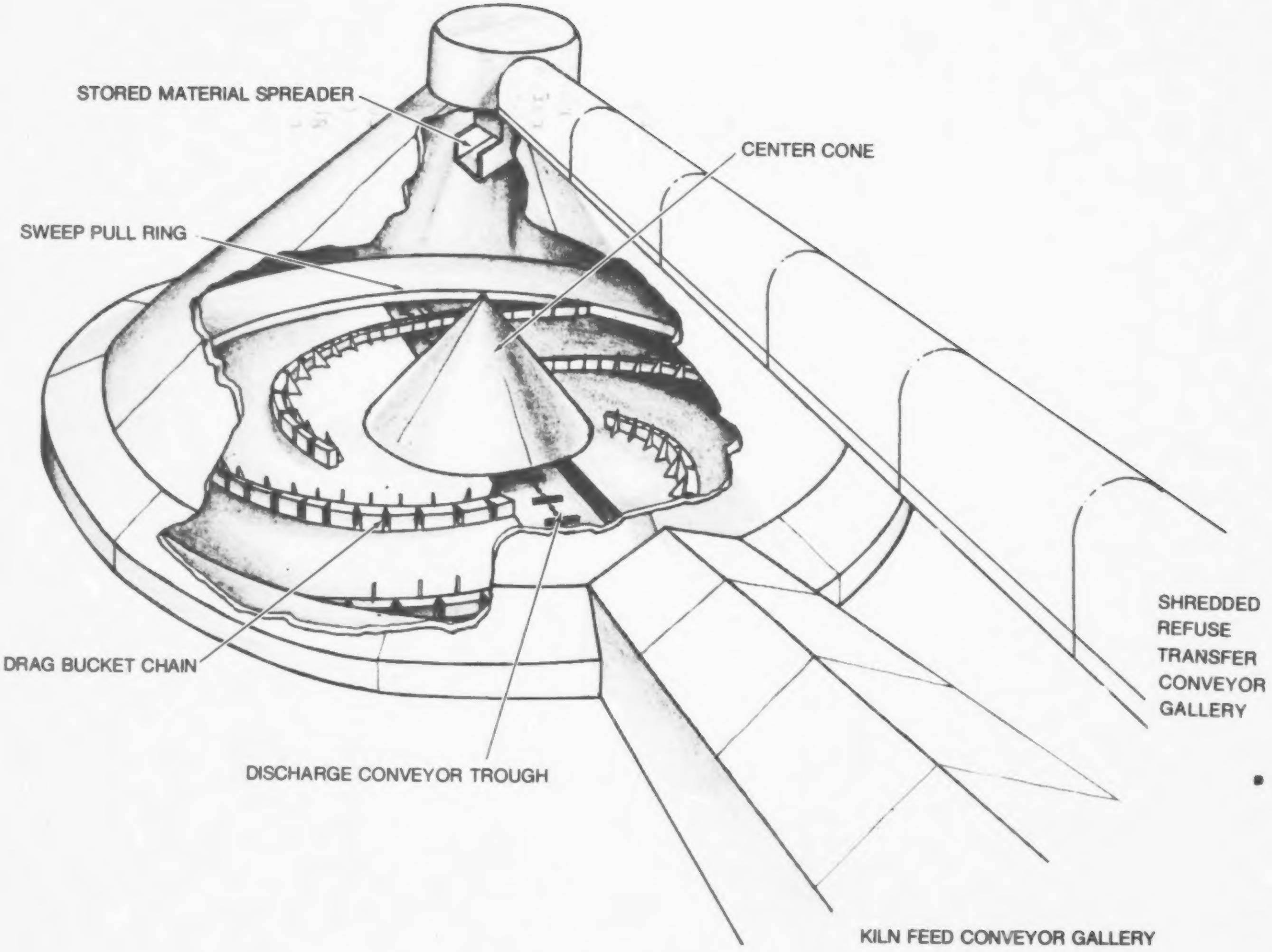

STORED MATERIAL SPREADER
CENTER CONE
SWEEP PULL RING
DRAG BUCKET CHAIN
DISCHARGE CONVEYOR TROUGH
SHREDDED REFUSE TRANSFER CONVEYOR GALLERY
KILN FEED CONVEYOR GALLERY

Figure 28. Schematic of the storage and recovery unit.

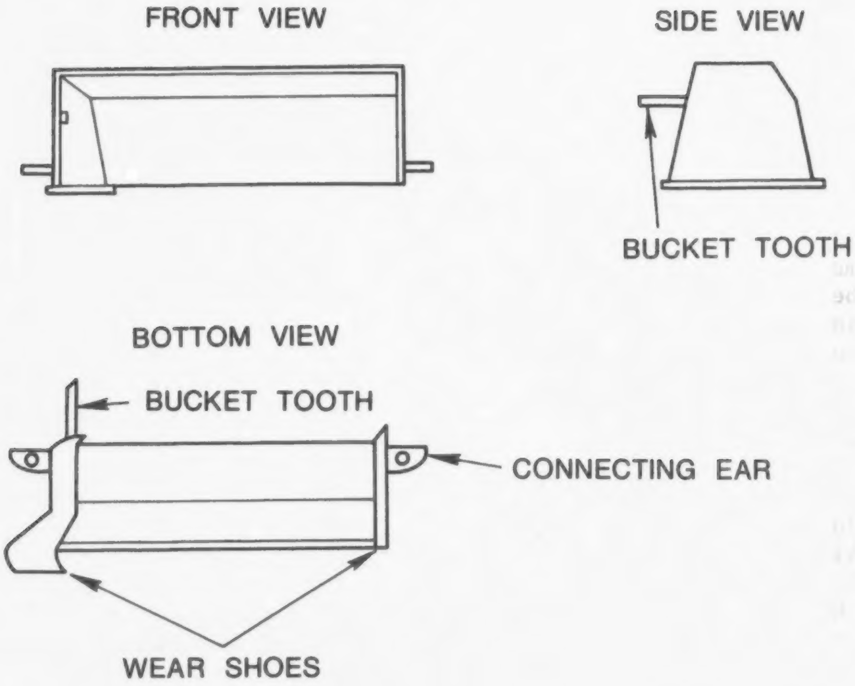

FRONT VIEW
SIDE VIEW
BUCKET TOOTH
BOTTOM VIEW
BUCKET TOOTH
CONNECTING EAR
WEAR SHOES

Figure 29. Buckets used in the storage and recovery unit.

for both the conveyor return run and personnel access. Steel bars were spaced at intervals across the top of the trough to reduce the waste load bearing on the conveyor. The conveyor consists of two runs of welded-steel, box-type drag chains. In addition, the trough was equipped as follows with a waste-level sensor installed near the drag conveyor discharge. A weighted bar was pinned to the center of a freely turning rod which lies across the trough. One end of the bar rests on the conveyor. When the cross rod pivots with the rise or fall of the waste level, its rotation provided the means for measuring the height of the waste level.

To supply the thermal processing system with refuse at the desired rate, the discharge conveyor was regulated as follows by the control room operator. First, the mass per unit time of the refuse carried on the kiln feed conveyor, as indicated by the signal transmitted from the weight scale on this conveyor, was compared with the corresponding mass per unit time established for the thermal processing system. To match the respective mass rates, the speed of the discharge conveyor was varied. Since the effectiveness of the conveyor operation depended on maintaining the conveyor waste level at 90 percent of capacity, the speed of the motor-driven ring pulling the bucket chains was also varied according to the signal transmitted by the waste-level sensor.

The discharge conveyor and ring speeds could be regulated in an automatic, a semiautomatic, or a manual mode. In the automatic mode, the ring speed was automatically controlled to maintain the conveyor waste level at 90 percent of capacity. The operator established the mass per unit time for the thermal processing system and the conveyor speed was automatically adjusted for a waste discharge at a corresponding mass per unit time. In the semi-automatic mode, the operator established the volume per unit time of the waste to be discharged by the conveyor and the speeds of both the conveyor and the ring were automatically controlled to maintain the set volume rate. In the manual mode, the operator regulated the speeds of both the conveyor and the ring to obtain a desired mass or volume rate. The control circuit protected the conveyor from jamming in the automatic and semi automatic modes, but not in the manual mode.

The discharge conveyor was interlocked with both the kiln feed conveyor and the ring-drive system. The first interlock stopped the discharge conveyor when the kiln feed conveyor was shut down and the second interlock stopped the bucket chain sweeping when the discharge conveyor was not running. However, the ring-drive system could operate in a timer mode which overrode these interlocks so that the bucket chains could be pulled for 30 seconds every 5 minutes to prevent their becoming fixed in the piling waste. The ring-drive system was also interlocked with the shredded refuse transfer conveyor so that this conveyor stopped when the drive system was not pulling the bucket chains. Still another interlock was provided through a high-level sensor in the floor storage area so that the transfer conveyor would stop when the silo storage capacity was reached.

Operating Experience

After the silo structure was erected, it had to be reinforced since it was not designed to support the additional weight of the stored material spreader and the shredded refuse transfer conveyor at the top of the silo cone.

Although the silo system had never been loaded to capacity, the measured bulk densities indicate that it could have handled the design capacity. While the shredder limitations precluded reaching the design input rate, the system attained the design output rate under optimal conditions.

As stated above, the silo storage and recovery system was intended to supply the thermal processing system with refuse over the weekend when no refuse was being delivered to the plant. However, the refuse stored on Monday in an empty silo would remain at the bottom of the pile until the weekend when the silo was emptied. If the silo was not completely emptied over the weekend, the refuse at the bottom of the pile would not be removed for at least another week. In actual operation the silo was rarely emptied and the refuse at the bottom of the pile remained in storage for several months. The extended storage resulted in an extremely dense mass of refuse that had to be removed manually.

In addition to the refuse compacting at the floor level because of extended storage and the bucket action, the bucket function of loosening and carrying the waste was further impeded because of the shredder failure to perform to design specifications. Waste pieces larger than 15 cm (6 in.), such as textile strands and wires, so intermingled with each other and other refuse that they both made the bucket digging difficult and caused bridging, especially along the silo walls, that prevented the waste above from falling (see Figure 30). Moreover, as the pile diameters decreased, the refuse was still more difficult to remove because of the fewer number of buckets contacting the refuse in the bucket chain sweep. In the early silo operation, the last 100 tons of waste had to be loosened with pitchforks before the buckets could remove the waste (Figure 31).

On one occasion when shredded waste that had been stored in the silo for several months caught fire and was thoroughly wetted by the fire department, it became the equivalent of paper mache. The mass was so dense that several hundred sticks of dynamite had to be exploded in the debris before it was loose enough for manual removal.

The measured bulk densities of the refuse in the bucket chains were about half the design densities. Moreover, the bucket breakup of the waste compacted on the floor further decreased the bulk density of the waste removed by the buckets. Consequently, to supply the discharge conveyor with refuse at the design mass rates and to provide the additional bucket force to break up the compacted refuse, the motor-driven ring for the bucket chain sweeps had to be operated at speeds up to 4 times the design speed.

To limit the increase in the speed of the bucket chain sweeps, the buckets, the bucket chains, and the bucket chain sweep area were all modified to make the refuse removal more effective. To this end, teeth were installed at the face of each bucket (Figure 32). Fabricated from 1-inch-square bar stock, the teeth lengths ranged from 6 to 12 inches according to the chain

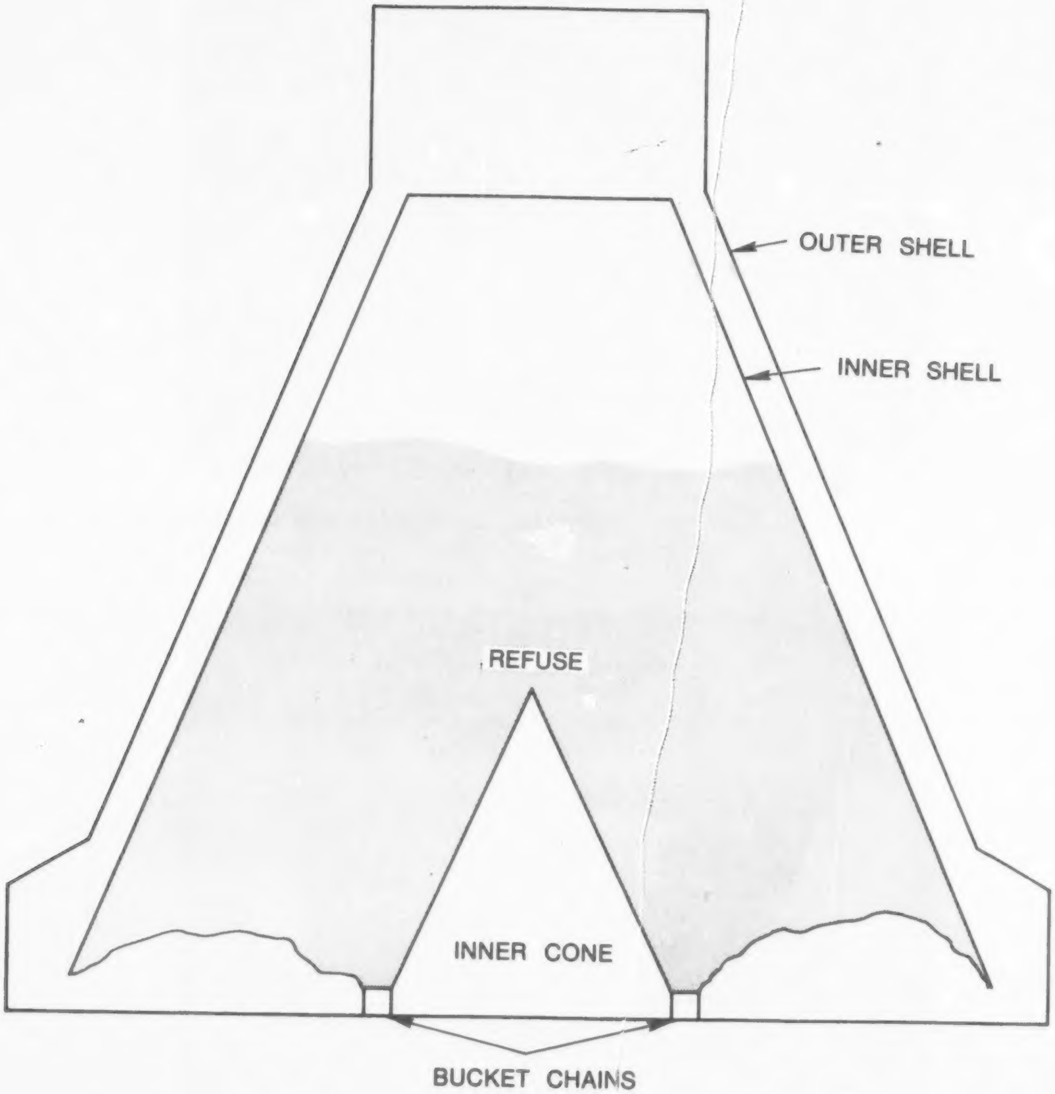

OUTER SHELL
INNER SHELL
REFUSE
INNER CONE
BUCKET CHAINS

Figure 30. Bridging of refuse against silo walls.

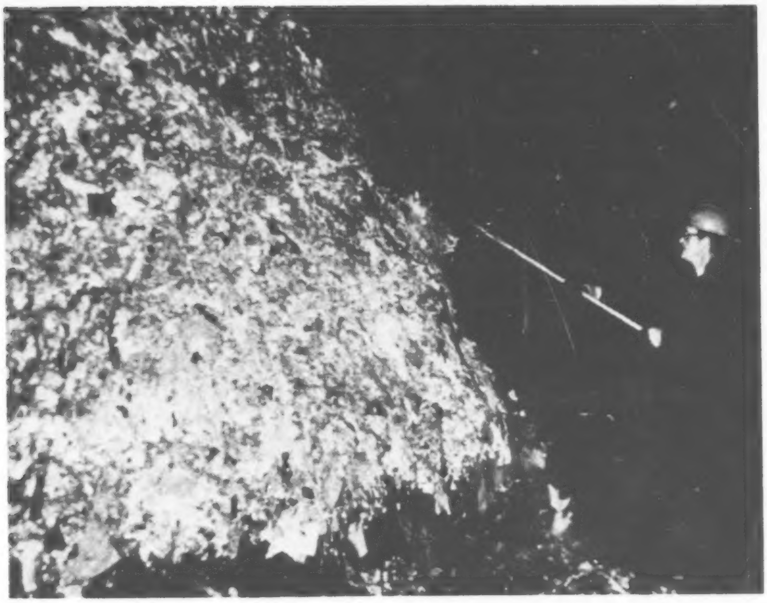


Figure 31. Loosening of the waste in the storage and recovery unit.

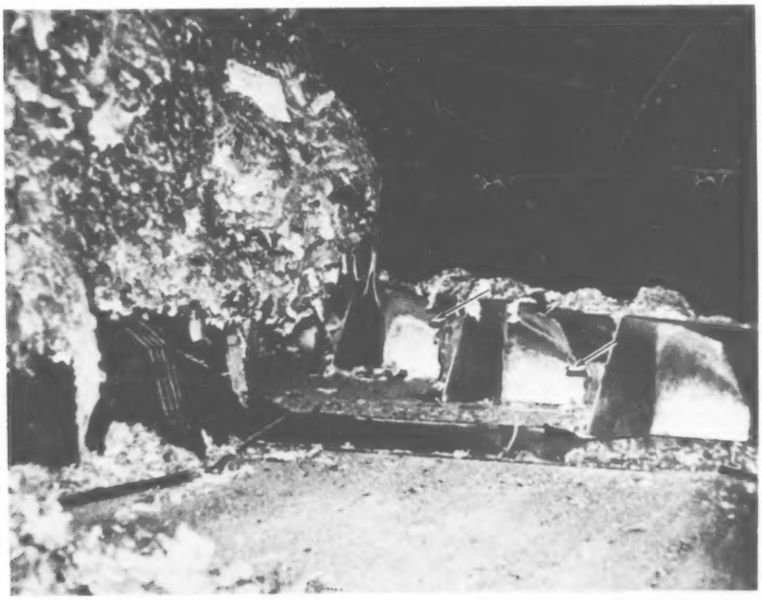


Figure 32. Buckets undercutting the refuse pile in the silo.

location of the buckets in which they were installed. However, the teeth lost their effectiveness as they became bent. To improve the bucket performance and wear, the manufacturer recommended using buckets twice as large as the existing ones.

The bucket chain and the bucket chain sweep area modifications were intended to increase the refuse removal capability by increasing the bucket contact with the refuse pile. Accordingly, the original floor-centered cone was replaced by a larger one with a 7-m (23-ft) base diameter and a 9-m (30-ft) height to both reduce the sweep area and to cause a better waste distribution for a proportionately greater bucket chain contact with the refuse pile. Providing further increase in the chain-refuse contact was the replacement of the original four chains with 10 buckets each by three chains with 20 buckets each. The three chains rather than four were used in the later configuration to prevent chain interference and jamming because of the greater number of buckets in each of the three chains (Figures 33 and 34). The lack of sufficient operational time precluded determining the relative wear of the three and four bucket chains.

Other changes to improve the waste removal operation included improving the waste storage conditions so that the waste compacting could be minimized. To this end, the silo was emptied periodically with intervals less than a month, and the maximum amount of waste stored in the silo was limited to 450 Mg (500 tons).

The high speeds of the bucket chain sweeps greatly increased the wear ratio of the bucket shoes and the silo floor. After tests indicated that the shoe wear rates were such that the shoes would have an effective life of only 2 months, the geometries and materials for an alternative shoe were investigated (Figures 35 to 38). As shown in Table 14, Astrolloy proved to be the most desirable material. However, since this material would extend the effective shoe life to only 5 months, it was unsatisfactory.

The floor wear was particularly important because of the high cost to repair or replace the floor. Monsanto determined the floor wear rate by measuring the elevation of the silo floor at various locations before and after a certain period of operation (Figure 39). As shown in Table 15, test results projected that the floor would wear out (floor level reduced by 100 mm (4 in.), after 80 operational days. This projection compared well with the actual figure when the floor wear-out was evidenced by the exposure reinforcing steel in the floor concrete. By this time, 67,000 Mg (74,000 tons) of refuse had been processed for an equivalent of 80 operational days with a refuse throughput of 907 Mg (1000 ton) per day. Much of the high rate of floor wear was due to construction materials not being of the high-grade, wear-resistant types recommended by the manufacturer. Although a floor resurfacing with flint aggregate and epoxy binder would have extended the floor surface life, it would still have worn out too soon if the high speeds of the bucket chain sweeps had been continued.

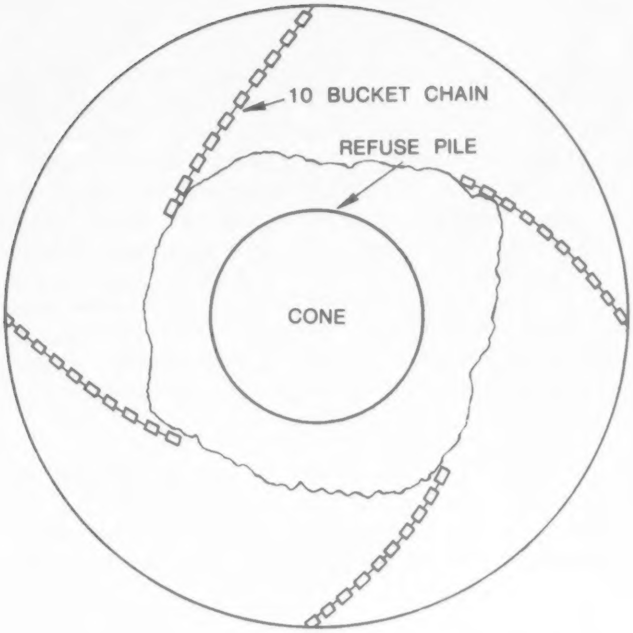

10 BUCKET CHAIN
REFUSE PILE
CONE

Figure 33. Ten bucket chains contacting the refuse pile in the silo.

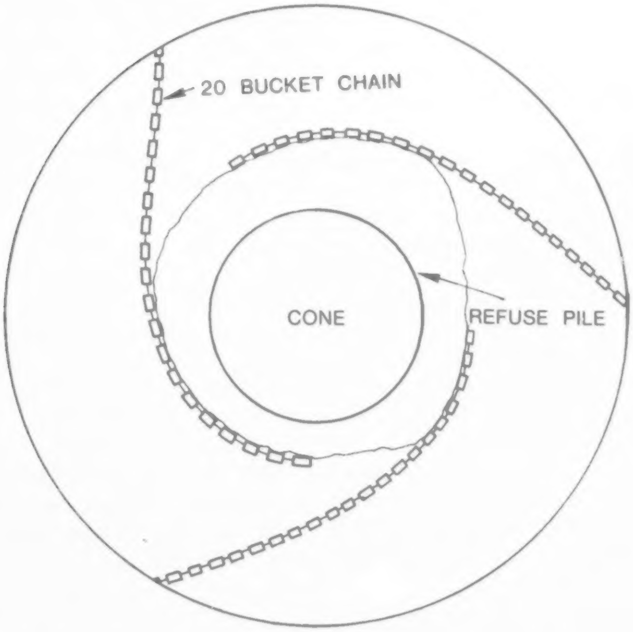

20 BUCKET CHAIN
CONE
REFUSE PILE

Figure 34. Twenty bucket chains contacting the refuse pile in the silo.

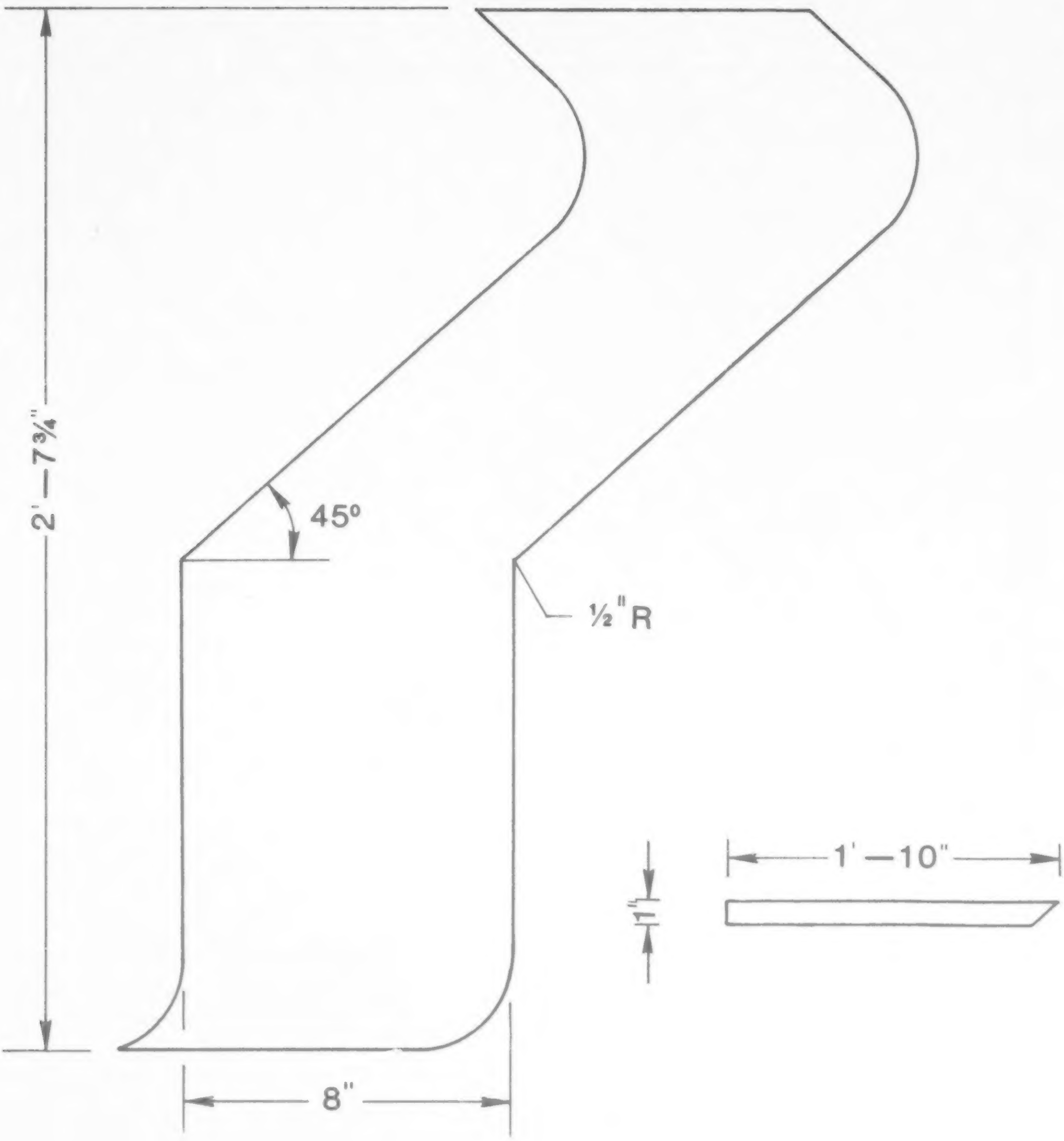

2'—7¾"
45°
½"R
1'—10"
1"
8"

Figure 35. Uniform width bucket wear show (type B).

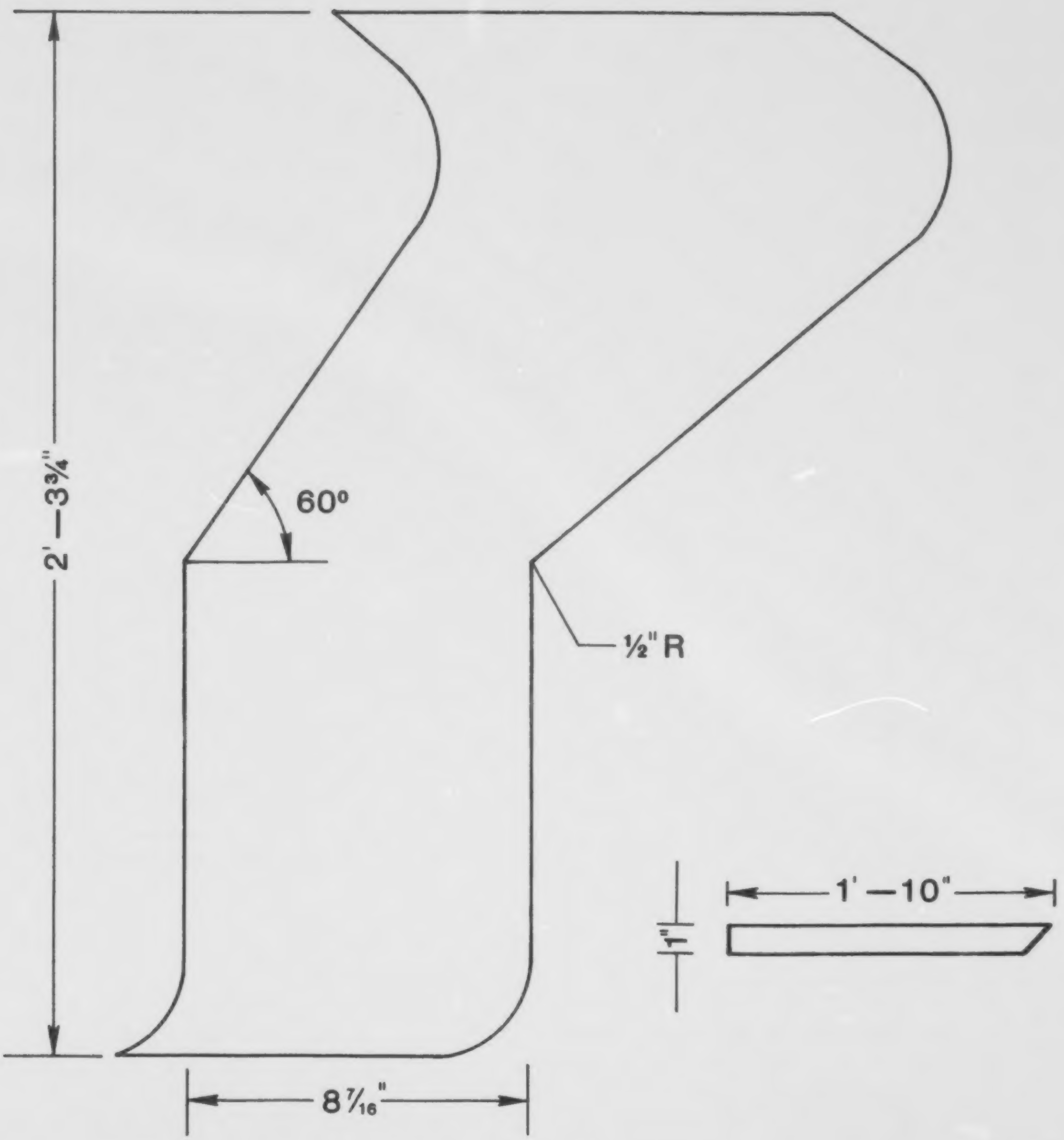

2' —3¾"
60°
½" R
8 7/16"
1' —10"
1"

Figure 36. Differential width bucket wear shoe (type C).

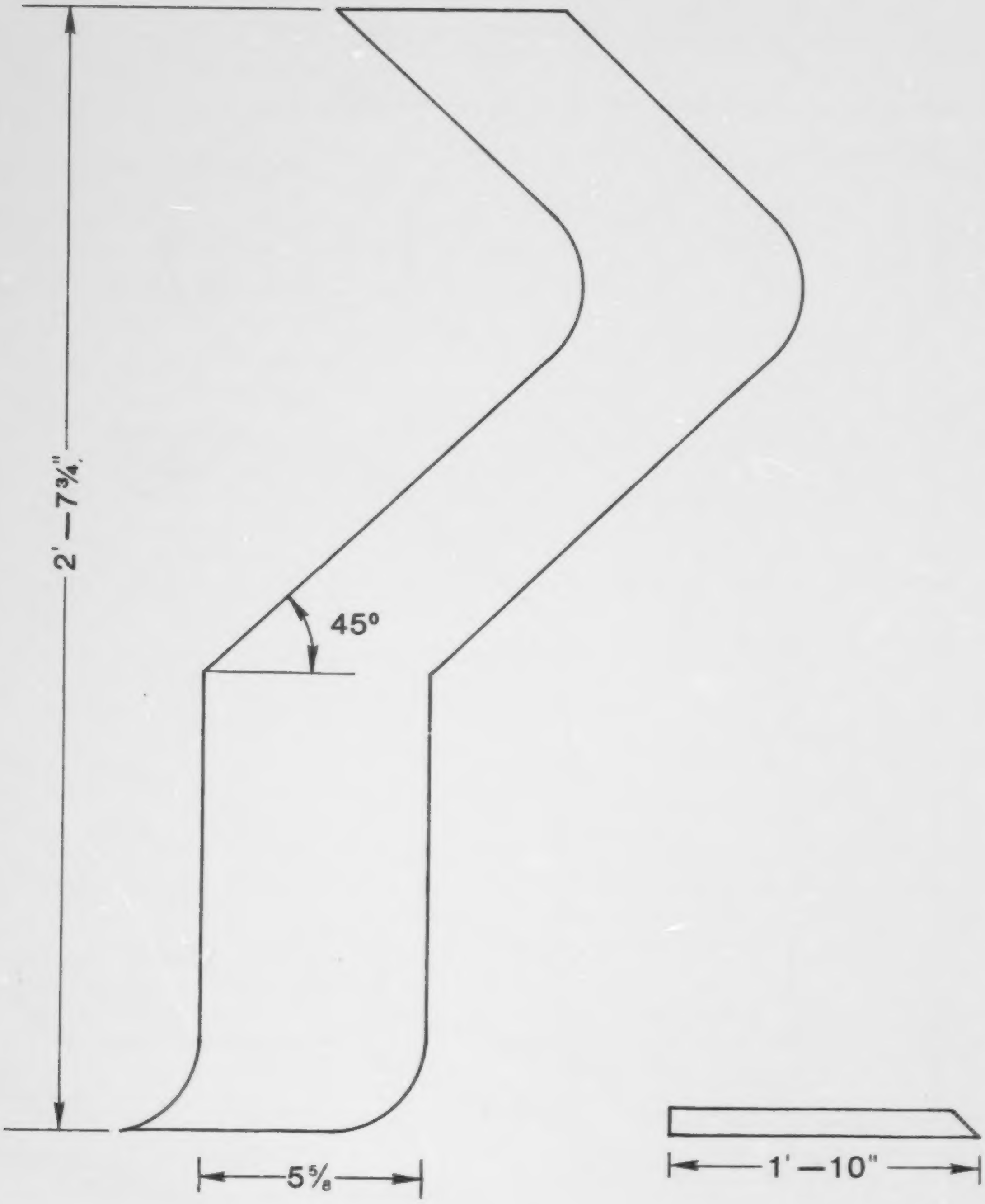

2' — 7¾"
45°
5⅝
1' — 10"

Figure 37. Elongated bucket wear shoe (type D).

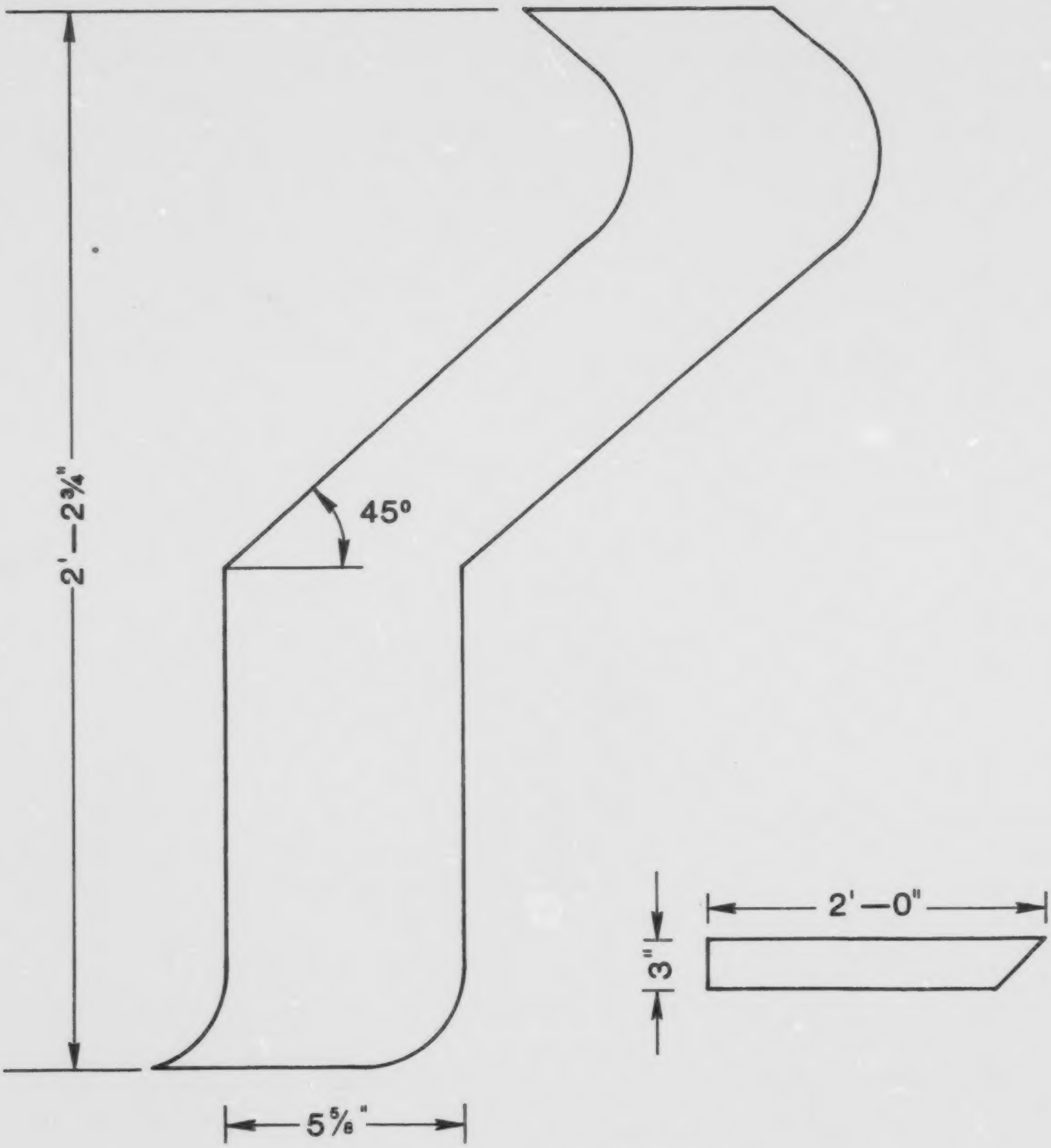

2'—2¾"
45°
5⅝"
2'—0"
3"

Figure 38. Regular bucket wear shoe (type E).

TABLE 14. LIFE OF BUCKET WEAR SHOES*

String #	Bucket #	Shoe Type	Material	Life (Hours)
1	1	C	ASTRALLOY	6181
	2	C	ASTRALLOY	2809
	3	C	ASTRALLOY	1478
	4	C	ASTRALLOY	7083
	5	C	ASTRALLOY	8395
	6	C	Tl-Steel	2481
	7	C	Tl-Steel	2809
	8	C	Tl-Steel	3222
	9	C	Tl-Steel	3222
	10	C	Tl-Steel	2229
2	1	B	Tl-Steel	1976
	2	B	Tl-Steel	2481
	3	B	Tl-Steel	1976
	4	B	Tl-Steel	2229
	5	B	Tl-Steel	1976
	6	B	Tl-Steel	2073
	7	B	ASTRALLOY	2881
	8	B	ASTRALLOY	3076
	9	B	Tl-Steel	1842
	10	B	Tl-Steel	1552
3	1	D	ASTRALLOY	3695
	2	D	ASTRALLOY	3076
	3	D	ASTRALLOY	4223
	4	D	ASTRALLOY	2437
	5	D	ASTRALLOY	2437
	6	D	Tl-Steel	1475
	7	D	Tl-Steel	1209
	8	D	Tl-Steel	1225
	9	D	Tl-Steel	1060
	10	D	Tl-Steel	1129
4	1	E	ASTRALLOY	3076
	2	E	ASTRALLOY	2054
	3	E	ASTRALLOY	4223
	4	E	ASTRALLOY	1965
	5	E	ASTRALLOY	2566
	6	E	Tl-Steel	2172
	7	E	Tl-Steel	1739
	8	E	Tl-Steel	2352
	9	E	Tl-Steel	1642
	10	E	Tl-Steel	1603

*Monsanto Modification Evaluation, A09-211, 10/4/76, Unpublished data.

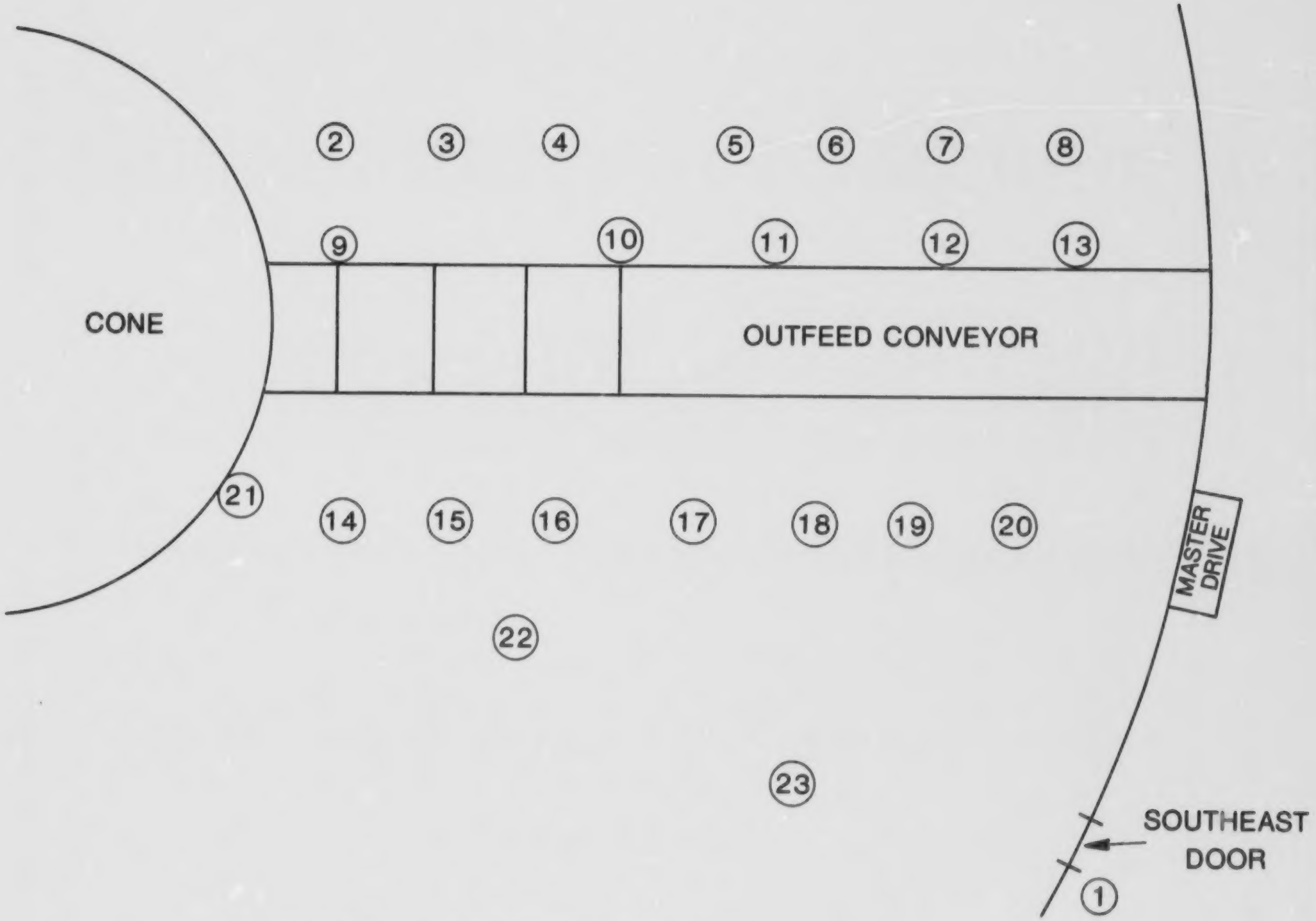

②
③
④
⑤
⑥
⑦
⑧
⑨
⑩
⑪
⑫
⑬
CONE
OUTFEED CONVEYOR
㉑
⑭
⑮
⑯
⑰
⑱
⑲
⑳
MASTER DRIVE
㉒
㉓
SOUTHEAST DOOR
①

Figure 39. Floor wear measurement points.

TABLE 15. FLOOR WEAR DATA*

4/30/76 - 9/30/76

680 Hours of Operation

Point	Elevation Difference mm	Wear Rate mm/day
2	4.57	0.16
3	7.32	0.26
4	8.39	0.31
5	14.94	0.52
7	36.27	1.26
8	36.27	1.26
9	4.27	0.15
10	5.79	0.21
11	5.79	0.21
12	5.79	0.21
13	5.79	0.21
14	4.27	0.15
15	6.71	0.24
16	6.71	0.24
17	11.28	0.40
18	14.94	0.52
19	19.51	0.69
21	1.22	0.04
23	19.51	0.69

*Monsanto Modification Evaluation, A09-210, 10/4/76, Unpublished data.

While the silo floor was still usable for bucket chain operation, floor surfacing worn away from the top edge of the trough had exposed the trough side plates to bucket snagging. Consequently, a sacrificial wear plate was installed at the trough edge to protect the plates.

Occasionally when the discharge conveyor was not running, waste accumulating above the trough had locked the conveyor in place. Since the piled refuse precluded working from above, the conveyor had to be released by jogging the drive motor at the motor site or by working in the access tunnel to remove refuse through trough openings that were cut into the side of the trough for such unjammings. The jamming was aggrevated when the bars across the trough had to be removed because of oversize particles, such as textile strands and wires, bridging over the trough and preventing refuse from falling onto the conveyor. In addition, the high discharge conveyor speeds required to meet the design refuse discharge ratio caused excessive wear on the drag chains.

Refuse frequently jammed at the area where the discharge conveyor dumped refuse into the hopper supplying the kiln feed conveyor. In this area, the discharge conveyor passed under the silo shell and the discharge conveyor drive motor. As the conveyor emerged from the silo where the piled waste had compacted the refuse on the conveyor, the exiting refuse would expand and contact the silo wall and drive motor above. The clearance was inadequate because it was based on the design bulk densities which, as mentioned above, were much more than those measured. In addition to a suggestion to increase the clearance, the manufacturer had recommended using multiple discharge conveyors to improve performance as well as to minimize jamming. Initially, the hopper convergence made the jammings more severe. However, the hopper was later modified to eliminate the convergence. Jammings at this area were also caused by frozen or low-density refuse slipping on the kiln feed conveyor. These jammings were prevented by coating the conveyor belt with belt dressing (adhesives) and stationing a man at the site for refuse clearing as jams started.

After the silo floor had worn out, the silo system was operated during emergency situations only with a front-end loader used to push the refuse onto the discharge conveyor. To permit the loader access and operation, a door was installed in the silo wall and the bucket chains and floor-centered cone were removed. While the discharge conveyor could be loaded properly, the manual operation precluded using the waste discharge rate controls, and the loader could not be operated when waste was dumped into the silo because of the excessive dust. Ultimately, as mentioned above, the operation of the entire silo system was suspended indefinitely.

Maintenance

The storage and recovery unit required extensive routine and emergency maintenance. Much of the plant downtime during the early demonstration period was due to failure in this system. The following paragraphs summarize some of the more significant maintenance experiences.

The bucket chains had to be frequently repaired or replaced because of damage sustained when they were buried under the waste piles. The replacement of the bucket wear shoes every 2 months requires about 100 man-hours.

One of the drive motors for the ring pulling the bucket chains had to be rebuilt twice because of water damage when water backed up into the motor pit when the wastewater lift station failed. To reduce the drive ring vibration, the original drive sprockets for the ring were replaced with machine-cut sprockets. The oil misters on these sprockets required routine repair and dust and debris cleaning. The drive ring broke twice and had to be welded each time. Although the wheels carrying the drive ring were routinely lubricated and cleaned of debris, their bearings occasionally failed because of glass grit. The guide rails for the drive ring had to be straightened frequently.

Both the motor and the head pulley of the discharge conveyor had to be replaced because of damage sustained when they were overloaded during conveyor jams. After the head pulley bearings and bearing grease seals failed because of glass grit and had to be replaced, a shield was installed to protect the bearings.

Table 16 summarizes the routine silo system maintenance recommended by Atlas and Monsanto.

THERMAL PROCESSING MODULE

As indicated by the shaded areas in Figure 40, the thermal processing module begins with the shredded refuse being conveyed to ram feeders for the subsequent gasification and combustion of the refuse to yield gaseous products for the production of steam in the energy recovery module and ends with the boiler flue gases being cleaned of acid and particulate before their discharge through a dehumidifier to the atmosphere.

In this module, much of the processing and equipment, particularly the kiln, is unique to the Landgard process. The shredded refuse is thermally processed to produce combustion gases with sensible heat and relatively inert residue, that is, some uncombusted char along with ash and other inert solids. Most, but not enough, of the acid and particulate in the boiler flue gas were removed by the original wet gas scrubber. Of various modifications and innovations to increase the particulate removal, only a surfactant addition was able to reduce the particulate level of the gas to comply with Federal standards but not enough to meet the State of Maryland requirements. Consequently, it was decided to replace the scrubber with an electrostatic precipitator.

As discussed in the preceding section, the shredded refuse was designed to be fed from the transfer tower to either the storage and recovery unit before its discharge onto the kiln feed conveyor or the bypass chute for its direct discharge onto the kiln feed conveyor. While the storage and recovery unit was operative, a belt scale on the kiln feed conveyor measured the mass rate of the refuse and thereby provided the means for controlling the amount

TABLE 16. STORAGE AND RECOVERY UNIT PREVENTIVE MAINTENANCE SCHEDULE

Daily

Watch pull ring one complete revolution.
Inspect wheels for normal operation.
Listen for abnormal sounds.
Inspect sweep drive assembly, chain over sprockets, sprockets, keys bearings, outfeed chain, outfeed drive and chain tension.
Check oil level in mist resevoir.

Weekly

Check discharge conveyor gear reducer and gear reducers in storage section.
(Winter - Paradene 475)
(Summer - Paradene X1000)

Monthly

Check oil mist lubricator for proper function, (be sure it is misting) the pressure should be 40 psi on top gauge.
Check Falk speed reducers for abnormal heat, noise, or leakage.
Check random pins on buckets for wear.
Lubricate drag and drive chain (Paradene 430).
Grease verticle wheel supports, thrust wheel axles, pillow block bearings, and reducers (LiEP2).

Quarterly

Change oil in discharge conveyor gear reducer.
(Winter - Paradene 475)
(Summer - Paradene X1000)
Lubricate level paddle on discharge conveyor (LiEP2).

Semiannually

Check drive couplings, bucket wear plates, buckets for wear, grizzley plates for wear and damage, pins on buckets, and replace as required.
Change oil in sweep speed reducer, and discharge conveyor.
(Winter - Paradene 475)
(Summer - Paradene X1000)
Check drive coupling lubrication (LiEP2).
Lubricate polyspeed motor on sweeps (LiEP2).
Check for contaminates.

Annually

Change drive couplings, lubrication (LiEP2).

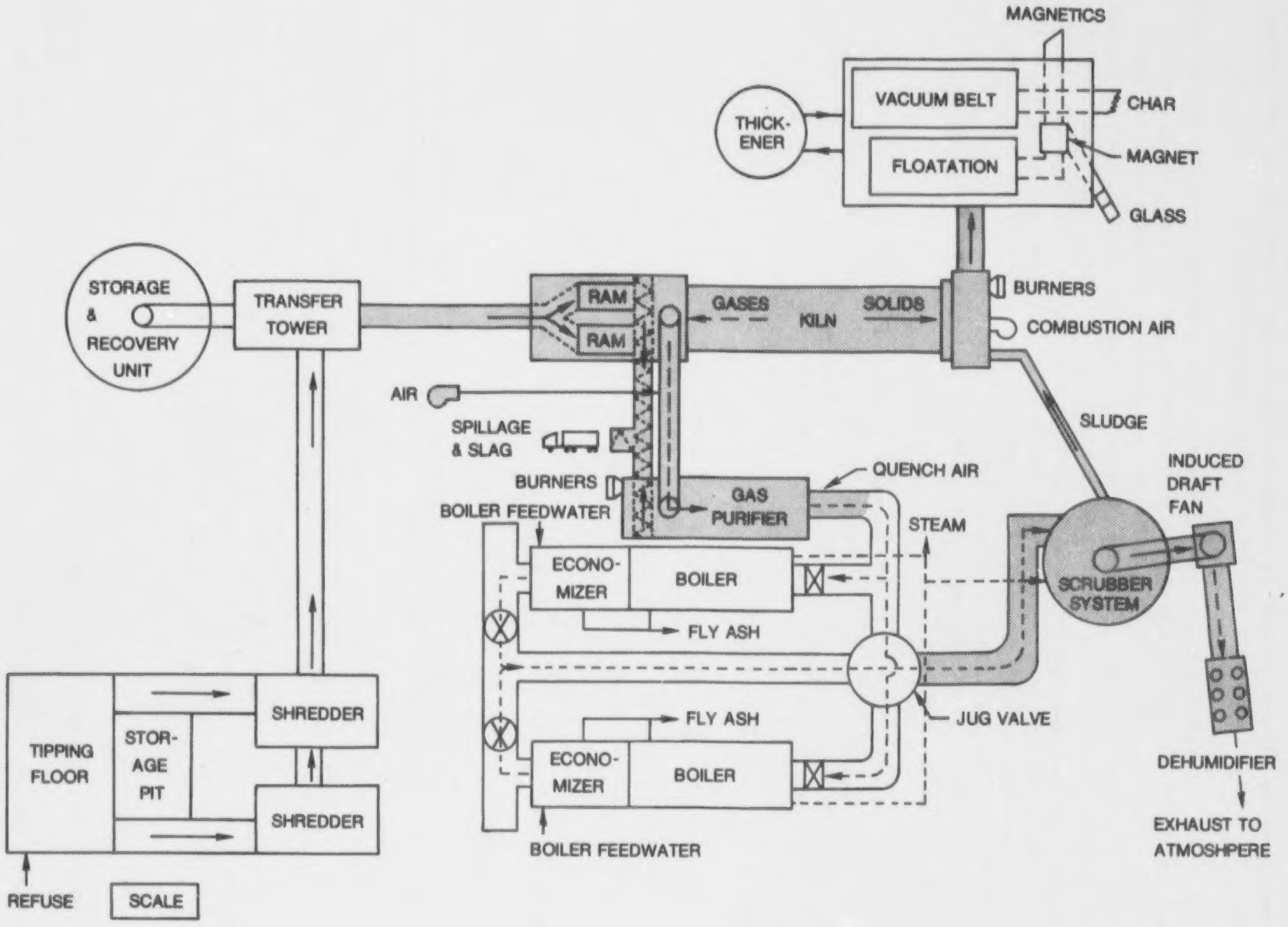

MAGNETICS
VACUUM BELT
CHAR
THICK-ENER
FLOATATION
MAGNET
GLASS
STORAGE & RECOVERY UNIT
TRANSFER TOWER
RAM
RAM
GASES
KILN
SOLIDS
BURNERS
COMBUSTION AIR
AIR
SLUDGE
SPILLAGE & SLAG
BURNERS
QUENCH AIR
GAS PURIFIER
INDUCED DRAFT FAN
BOILER FEEDWATER
STEAM
ECONO-MIZER
BOILER
SCRUBBER SYSTEM
FLY ASH
TIPPING FLOOR
STOR-AGE PIT
SHREDDER
SHREDDER
JUG VALVE
FLY ASH
ECONO-MIZER
BOILER
DEHUMIDIFIER
BOILER FEEDWATER
EXHAUST TO ATMOSHPERE
REFUSE
SCALE

Figure 40. Thermal processing module (shaded area).

of refuse delivered to the ram feeders. However, with the discontinuance of the storage and recovery unit, the mass rate of the shredded refuse stream to the ram feeders can no longer be measured since the discharge of the silo bypass chute is upstream of the belt scale design position.

The ram feeders were designed to convey the shredded refuse to the kiln by extruding it through confining tubes in order to maintain an air seal since the kiln operates under a negative pressure. Within the kiln, which is declined and continuously rotating, the refuse tumbles forward while undergoing thermal reactions to first gasify most of the waste and then combust enough of the gas and carbon char to sustain the thermal processes. As the residue falls at the lower end into a water seal and quench tank with a drag conveyor for the residue removal, the combustion gases exit at the upper end to flow to the gas purifier. Fans supply the combustion air needed for the kiln, gas purifier, and various burners which provide supplemental heat and serve as ignition sources.

In the gas purifier, the combustion of the kiln off gases is normally completed as molten slag in the gas stream is thrown to the vessel walls to slide down to and out of a slag taphole. A two-fold screw conveyor in the water seal tank of both the slag taphole and the feed hood at the upper and refuse feed end of the kiln discharges the slag and other material into trucks for landfill disposal.

Two quench air dampers were retrofitted in the exit duct of the gas purifier to cool the gases sufficiently so that the initial slagging of the boiler tubes with molten slag would be eliminated. The additional air also completed the burning of any uncombusted gaseous products, As mentioned above, the wet gas scrubber, designed to reduce the particulate concentration in the boiler flue gases to prescribed levels, is being replaced by an electrostatic precipitator. Just before the dehumidifier, which completes the module, is the induced draft fan that pulls the combustion gases through the entire module.

Much of the thermal processing module is unique and developmental, and there is no redundancy in the module. Consequently, equipment and operational malfunctions have been numerous, and their occurrences have been critical since they have usually caused shutdowns of the entire plant. Among the major or critical components causing plant shutdowns are the refractory in the kiln and gas purifier, the ram feeders, the residue drag conveyor, the two-fold screw conveyor, and the induced draft fan. Among the operational problems have been the plugging of the slag taphole, which has caused plant shutdowns, the poor control and instability of the kiln thermal processing, and the excessive particulate level of the flue gases exiting the wet gas scrubber.

Kiln Feed Conveyor

Designed to receive shredded refuse from either the discharge conveyor in the storage and recovery unit or the by-pass chute, the kiln feed conveyor transfers the refuse into the dual ram feed hoppers where the refuse is forced into the kiln.

Description

Except for its 1.2-m (4-ft) width, the kiln feed conveyor is the same type of trough belt conveyor as the three shredded refuse conveyors discussed previously. The kiln feed conveyor rises on a 22° incline for the first 32 m (100 ft) and then smoothly levels to become horizontal. Its design average and surge capacities are 39 and 57 Mg (43 and 63 tons) of refuse per hour. In addition to emergency shutdown cords along each side, the kiln feed conveyor is interlocked with the ram feeder hydraulic pumps so that it stops when the pumps shut down.

Operating Experience

Designed to operate continuously with the kiln, that is, 24 hours per day, 7 days per week, the conveyor has generally operated according to this schedule except for a seventh day each week reserved for maintenance during the demonstration period.

The feed conveyor has had excessive spillage and slippage. Since the bulk density of the refuse averaged 90 kg/m^3 (5.6 lb/ft^3) as compared to the design bulk density of 208 kg/m^3 (13 lb/ft^3), the volumetric flow rate has been inadequate when the conveyor operates at design mass flow rates causing spillage. Spillage has been severe especially at the discharge of the by-pass chute where the feed conveyor has insufficient clearance for low-density refuse and at the feed conveyor discharge above the ram feed hoppers. To reduce the spillage, the conveyor belt speed was increased to 60 mpm (200 fpm).

As discussed above for the other inclined conveyor, slippage was due to dry, low-density, and frozen refuse. To reduce the slippage, the rubber dust curtains at the refuse transfer points along the feed conveyor were removed, and the feed conveyor was sprayed with belt dressing (adhesive coatings) to temporarily hold the refuse. However, the curtain removal allowed excessive dust, particularly from the vertically falling discharge of the by-pass chute, to disperse throughout the feed conveyor area.

Maintenance

Except for the following emergency situations, the kiln feed conveyor has generally required only routine proventive maintenance (Table 11). On three occasions, the conveyor was severly damaged by fire because of failure of the induced draft fan or refuse combustion in the ram feed hoppers. Possible means of preventing such damage would be using a pan conveyor in conjunction with the feed conveyor or installing a gate to shield the conveyor belt.

Belt Scale

When the kiln feed conveyor carried refuse from the storage and recovery unit, the belt scale on the conveyor sensed the mass per unit time and transmitted a signal to the control room where the measured mass per unit time was compared with the corresponding mass per unit time established for the refuse flow in the thermal processing system. If the two rates did not agree, the speeds of the bucket chain sweep and the discharge conveyor in the storage and recovery unit were changed accordingly.

Description

The belt scale is a Merrick Type L440E Weightometer incorporating a belt speed sensor, a weight signal transducer, and a totalizer. The scale is installed on an idler at an inclined part of the kiln feed conveyor.

Operating Experience

The belt scale had the same operational schedule as the kiln feed conveyor. Except for the failure of one circuit board and a totalizer measurement error of about 2 Mg (2 tons) per hour, the scale had no operational malfunctions or deficiencies. The totalizer measurement error was due to the mechanical splicer on the conveyor which could be corrected by replacing the existing splices with vulcanized one.

However, the function of the scale had been limited to the refuse dumped by the storage and recovery unit discharge conveyor. The scale placement is below the discharge point of the by-pass chute, and the scale cannot be moved above this point to weigh the refuse from the by-pass chutes because of the scale operational requirement that the conveyor run be continuously straight before as well as after the scale position. Since the silo system operation has been indefinitely suspended, the shredded refuse could now only be measured by installing a belt scale on the shredded refuse elevating conveyor.

Maintenance

The belt scale has required only periodic cleaning and calibration, monthly lubrication of the scale bearings, and semiannual lubrication of the speed sensor.

Dual Ram Feeders

As the kiln feed conveyor discharges the shredded refuse into dual ram feed hoppers, the ram feeder system serves the two-fold purpose of extruding the refuse into the kiln and of so compacting the refuse during the extrusion that the densified waste maintains an air seal for the kiln.

The kiln feed conveyor may also discharge the refuse onto a by-pass chute which slides in and out of the feed shroud above the hoppers. The by-pass chute was intended as a means of transfering refuse onto trucks for landfill disposal when the storage and recovery unit was being emptied.

Description

With reference to the cutaway view in Figure 41, refuse dumped into the feed shroud falls into two parallel, semicylindrical hoppers which are separated by a waste stream splitter. The ram feeder for each hopper is a

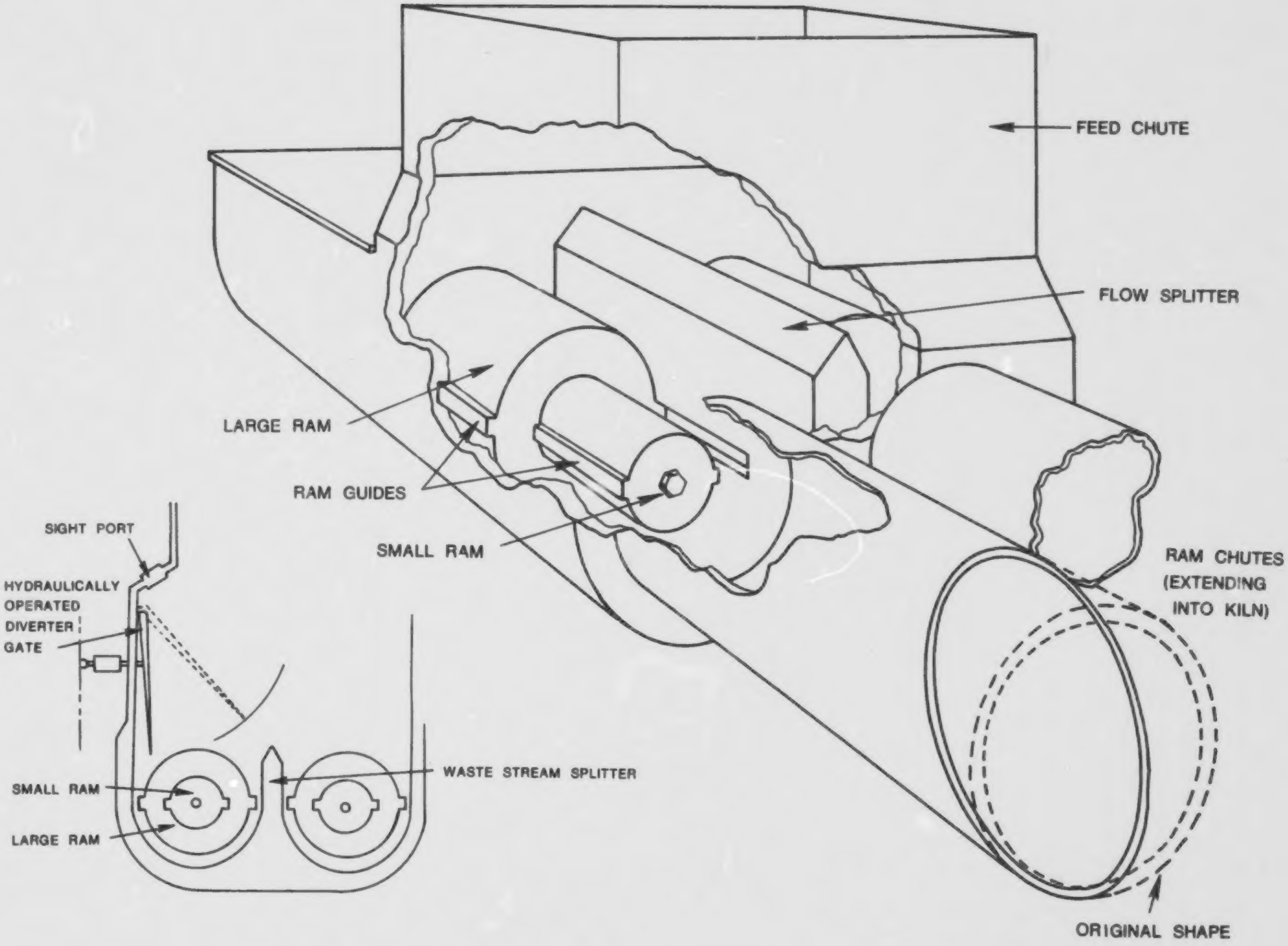

FEED CHUTE
FLOW SPLITTER
LARGE RAM
RAM GUIDES
SMALL RAM
RAM CHUTES (EXTENDING INTO KILN)
ORIGINAL SHAPE
SIGHT PORT
HYDRAULICALLY OPERATED DIVERTER GATE
SMALL RAM
LARGE RAM
WASTE STREAM SPLITTER

Figure 41. Schematic of the ram feeders.

two-piece telescopic cylinder. The outer cylinder, 1.2 m (4 ft) in diameter and 2.0 m (6 ft) in length, has side bars that move on nylon tracks along slots in the hopper walls; and the inner cylinder, 0.6 m (2 ft) in diameter and 0.8 m (2.5 ft) in length, also has side bars that similarly move on nylon tracks along slots in the inner circumferential area of the outer cylinder. When both cylinders are fully retracted, their front faces align with the rear wall. As the two cylinders advance as a unit, they serve as a single ram to push the refuse toward the outlet tube called a ram tube or snout. Then when the outer cylinder stops at the limit of its travel, the inner cylinder telescopes to act as a smaller-diameter ram.

Each ram feeder is activated under electrical control by a hydraulic system which is powered by a 100-hp motor. With a capacity for 170 liters (45 gallons) of hydraulic fluid per minute, each hydraulic system has a pressure override that increases the normal pressure of 10,345 kPa (1500 psig) to a maximum pressure of 20,685 kPa (3000 psig). The pressure override was intended to clear refuse jamming in the ram tubes.

Each ram feeder operates independently of the other and has a variable speed ranging from 30 seconds to 5 minutes per cycle. The independent operation and the variable speed were introduced both to adapt to a varying discharge load into the two hoppers and to supply the kiln with a fairly steady refuse flow. The ram feeders are interlocked to the kiln feed conveyor so that a complete feeder shutdown automatically stops the conveyor. The hoppers are also equipped with water sprays which can be manually activated in the case of a fire in the ram snouts or hoppers.

As the kiln feed conveyor continuously dumps refuse into the feed shroud, the waste falls directly into the hoppers or onto the cycling rams. When the outer cylinder of each ram feeder reaches the limit of its stroke, the inner cylinder telescopes under the continued hydraulic pressure to ram the refuse toward and into the ram tube until it strikes a mechanical switch at its full extension. Then the flow of hydraulic fluids reverses to retract the two cylinders. When both cylinders are completely retracted to complete the cycle, the start switch is activated to repeat the cycling.

The ram tubes extend from inside the ram feeder housing, through a feed hood, and then into the kiln. The feed hood is aligned with and contiguous to both the ram feeder housing and the kiln. Fabricated of 316 stainless steel to withstand the kiln temperatures, the tubes are approximately 1.2 m (4 ft) in diameter and 4 m (12 ft) in length, the tubes originally had internal baffles to restrict and further compact the refuse for the kiln air sealing.

Operating Experience

The ram feeders were designed for the same operational schedule as the thermal processing; that is, 24 hours per day, 7 days per week. However, because of the current plant operating and maintenance schedules, the ram feeders run only 6 days a week but still 24 hours a day.

Originally, the ram feeders were operated by a single set of controls in the control room. To provide the control room operator with visual imagery of the ram feeder performance, a closed-circuit television was installed with the camera positioned at the feeder sight port. However, after the camera was damaged several times by heat from fire that backed up from the kiln during induced draft fan failures, the camera was removed. While it was operative, the television monitoring did not provide an adequate view for proper control. Consequently, because of the criticalness of the ram feeder operation, a man was stationed at the sight port to inform the control room operator of the continuous feeder performance, and manual pressure override controls were installed near the feeders for local supportive control.

Among the operational problems has been the impossibility of conducting preventive maintenance in the ram feeder housing while the feeders are operating. In addition, when the feeders are jammed by waste that cannot be cleared with the high-pressure override, the entire plant must be shut down to allow manual removal of the waste jam. Also the reciprocating action of the ram feeders has caused excessive wear on the electrical connections to the mechanical sequencing switches mounted on the ram feeders.

Waste spillage behind and below the ram feeders poses a fire hazard. Dust and glassy grit accumulate in the hydraulic pumps and cause severe wear of all moving parts. The rotary equipment, therefore, should be placed in a sealed enclosure or moved far enough from the waste stream. In addition, the glassy grit severely abrades the nylon tracks that guide the motion of the ram cylinders.

Because of faulty design or fabrications, the original ram tubes or snouts, failed during the first heat-up when cooling water in the tubes boiled and burst the tubes. Unknown to the operating crew, the escaping water flowed into the kiln where it wetted the refractory lining as well as the refuse and impeded the kiln processing. Consequently, the ram snouts were replaced with newly designed ones made of 316 stainless steel. The new snouts, however, became badly deformed from intense heat in the feed hood and in the snouts themselves. Such heat (greater than 1000°C, 1800°F) was due to kiln process upsets and refuse fires within the snouts during ram jammings.

As a result of the snout deformation, the refuse flow in the snouts became so restrictive that numerous jams occurred within the snouts. To allievate the constriction, the baffles inside the tubes were removed and the snout ends were cut at a 45° angle (Figure 42). But then the waste compactness and in turn the air sealing were so reduced that the air leakage into the kiln increased the kiln processing temperature. To minimize the snout deformation, Monsanto recommended that snouts be constructed of 330 stainless steel and equipped with heat shields and ring stiffeners.

The hydraulic unit cooling system was originally a once-through water system using City water. Because of the low pressures of the plant water supply, the original system was changed to a dual system by adding a water recycling system which will be discussed later.

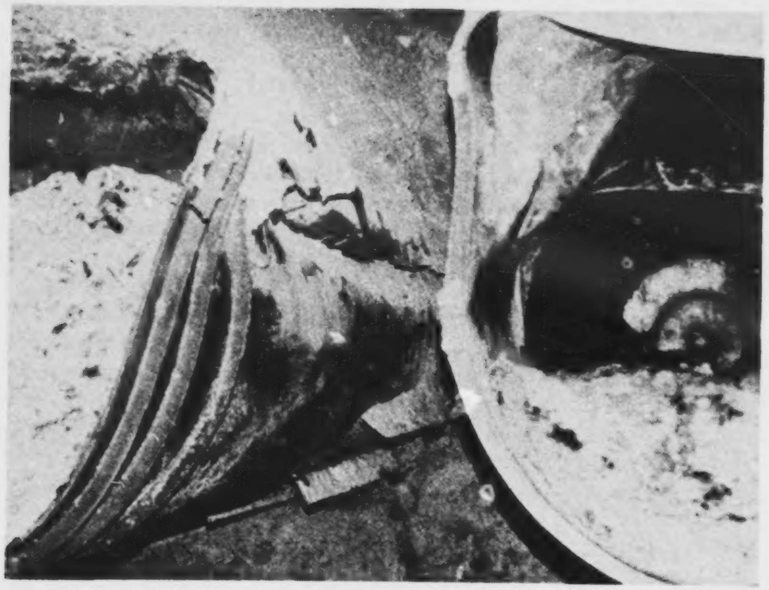


Figure 42. Deformed ram snouts.

To prevent refuse from falling onto a jammed feeder, a diverter gate was installed on the outside wall of each hopper and at a level just below the sight port (Figure 41). Each gate is a hinged flat plate which swings to the waste stream splitter when actuated by a 25-cm, pneumatic-powered cylinder controlled by a solenoid valve.

The hydraulic system seals have been damaged because of the corrosiveness of the Pydraul used as the working fluid in the hydraulic system. In addition, glassy grit and dust have impeded the operation of the system sequencing valve.

When only one ram feeder was operational from March 10 through March 18, 1977, it had an average output of only 25.3 Mg per hour (27.9 tph) whereas the design capacity for each feeder is 27 Mg per hour (30 tph). The output capability depends on the moisture content and the bulk density of the incoming refuse. At one point in time, water was added to the low bulk density refuse to improve the performance of the ram feeders. During the March operation, the moisture content was low compared with that in the summer, and the measured bulk densities, as discussed above, were generally much lower than the design bulk densities.

The hydraulic pipes originally installed on the ram feeders were replaced with hoses to better absorb the hydraulic shock. These hoses, however, frequently sustained leaks and breaks.

Maintenance

The hydraulic system has required considerable maintenance. For example, hoses have to be frequently repaired because of leaks or breaks sustained from high fluid pressure and pressure shock pulses, and O-rings have required routine replacement. The preventive maintenance schedule for the dual ram feeders is shown in Table 17.

TABLE 17. RAM FEED PREVENTIVE MAINTENANCE SCHEDULE

Weekly

Check cylinders and hoses for leaks or noise.
Check for smooth operation, visible wear, and neatness.
Check hydraulic package for pressure, leakage, noise, vibration, and shock.
Check hydraulic oil level (Pydraul 50-E).

Monthly

Check pressure setting on hydraulic valves and notify instrument technician to adjust as required to prevent system shock.
Check nylon shoes for wear - replace if necessary.
Check filters on the inlet and outlet of the pump (elements #361992 and #923070); clean or replace as required.
Lubricate large guides (Pyroplex EP2).
Lubricate small guides (Molycote).

Semiannually

Test for wear and proper operation.
Change filter elements (#361992 and #923070).
Lubricate motors (LiEP2).
Check motor, alarms, interlocks, oil heaters, limit switch cables, low hydraulic pressure.
Check and lubricate speed changer and indicator system.
Inspect all solenoid valves.
Clean and lubricate local control cabinets.

Annually

Megger Motor.
Grease motor bearings (LiEP2).
Calibrate ram feeder pressure gauges.
Change hydraulic reservoir fluid (Pydraul 50-E).
Review preventive maintenance schedule.

Kiln

The shredded refuse extruded into the kiln by the ram feeders is dried, pyrolyzed, and then combusted in a high-temperature, substoichiometric atmosphere. After this processing, the ash, other inert solids, and some uncombusted carbon char are discharged into a water quench for cooling before their removal by a drag conveyor.

In the Landgard process, the primary release of thermal energy takes place in the kiln during the endothermic pyrolysis reaction. In the kiln, the refuse is exposed to high temperatures in an oxygen deficient atmosphere and subsequently is chemically decomposed (pyrolyzed) into combustible, pyrolytic gases, such as CH_4, H_2, and other hydrocarbons. The heat to pyrolyze the refuse is supplied by combusting the carbon char, remaining after the pyrolysis reaction has been completed, and some of the pyrolytic gases.

Air and fuel oil to burn the char and provide auxiliary heat are injected at the discharge end of the kiln. The hot gas flow is counter to that of the refuse, and upon exiting the kiln in the area above the refuse entrance, the hot gases mix with air for combustion in the gas purifier (afterburner) which produces a hot gas stream for energy recovery.

Description

As shown in the cutaway views of Figure 43, the kiln is a refractory-lined, cylindrical, rotating, inclined vessel 6 m (20 ft) in diameter and 30.5 m (100 ft) in length. The kiln, along with the drive system and support trunnions, was manufactured by Kennedy Van Saun. The kiln processing is monitored by an optical pyrometer, thermocouples at each end of the kiln, and an O_2/CO_2 gas analyzer in the kiln feed hood. Burners at the discharge hood supply heat for system heat-up and initial combustion. Variable-volume fans inject combustion air into the kiln through inlets in the end of the discharge hood and through an air bustle (Figure 44) around the seal at the discharge end of the kiln.

The kiln shell is fabricated from 22 mm (0.875 m) thick mild steel with the exception of the first 46 cm (18 in.) of the feed end which is fabricated from 316 stainless steel. The ends of the kiln have stainless steel angles mounted on the steel shell to help hold the refractory (Figure 45). Axial slots 6 mm wide and 60 mm long in each end of the kiln on a 25-cm center allow for thermal expansion of the kiln shell, particularly at these points.

The kiln is lined with a 23-cm (9-in.) layer of Kaiser stainless steel fiber-reinforced, high-strength castable refractory. Variations in process temperatures along the kiln length have required different refractory materials in each of the processing zones (Table 18).

The internal surface of the kiln has two types of projections, called lifters, which move and disperse the trash in the vessel: plates or "flights" at the feed end of the kiln and pipes, or "spikes", further down the kiln in the processsing zone (Figure 46).

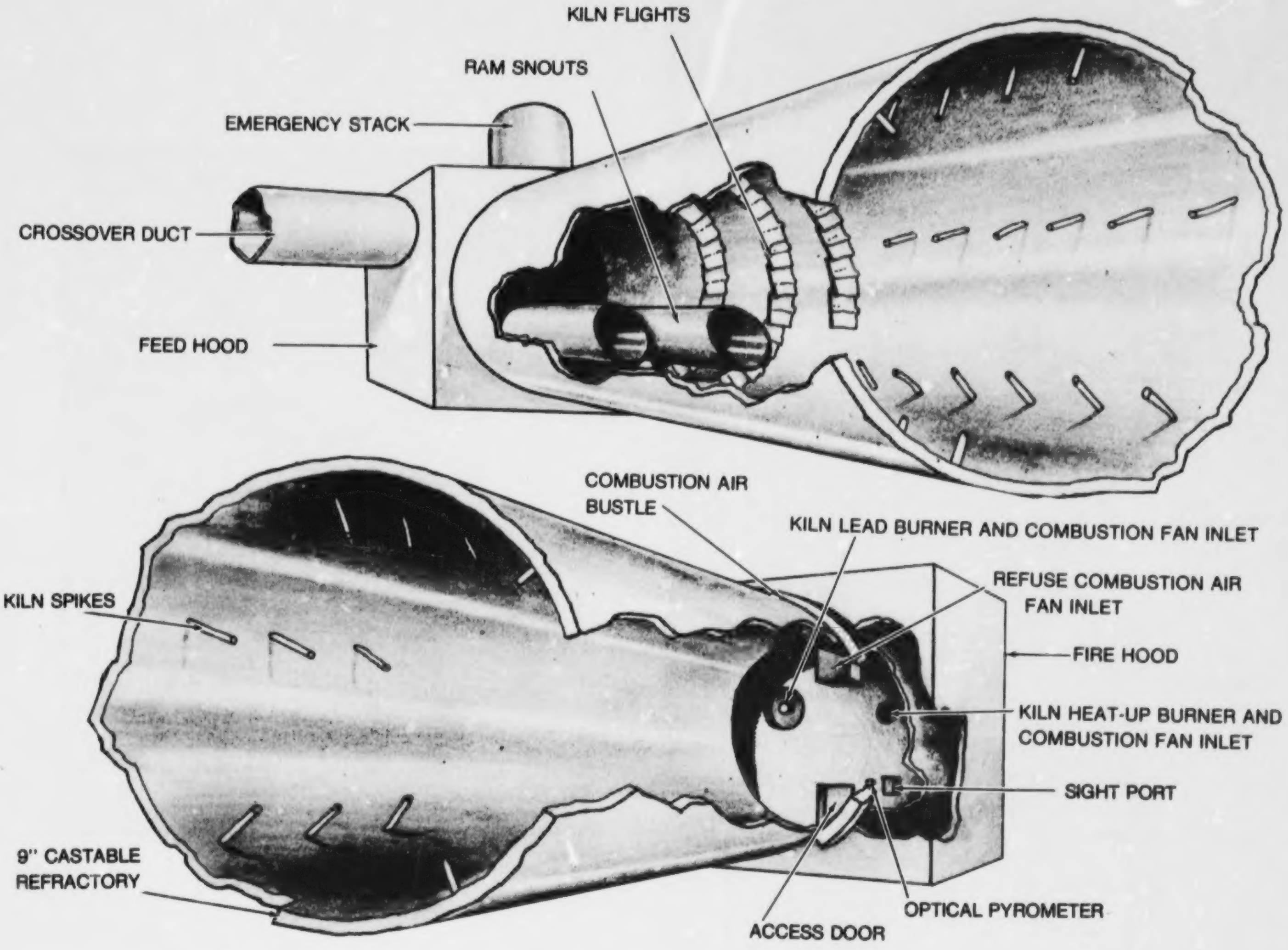

KILN FLIGHTS
RAM SNOUTS
EMERGENCY STACK
CROSSOVER DUCT
FEED HOOD
COMBUSTION AIR BUSTLE
KILN LEAD BURNER AND COMBUSTION FAN INLET
REFUSE COMBUSTION AIR FAN INLET
FIRE HOOD
KILN HEAT-UP BURNER AND COMBUSTION FAN INLET
SIGHT PORT
KILN SPIKES
9" CASTABLE REFRACTORY
OPTICAL PYROMETER
ACCESS DOOR

Figure 43. Schematic of the kiln.

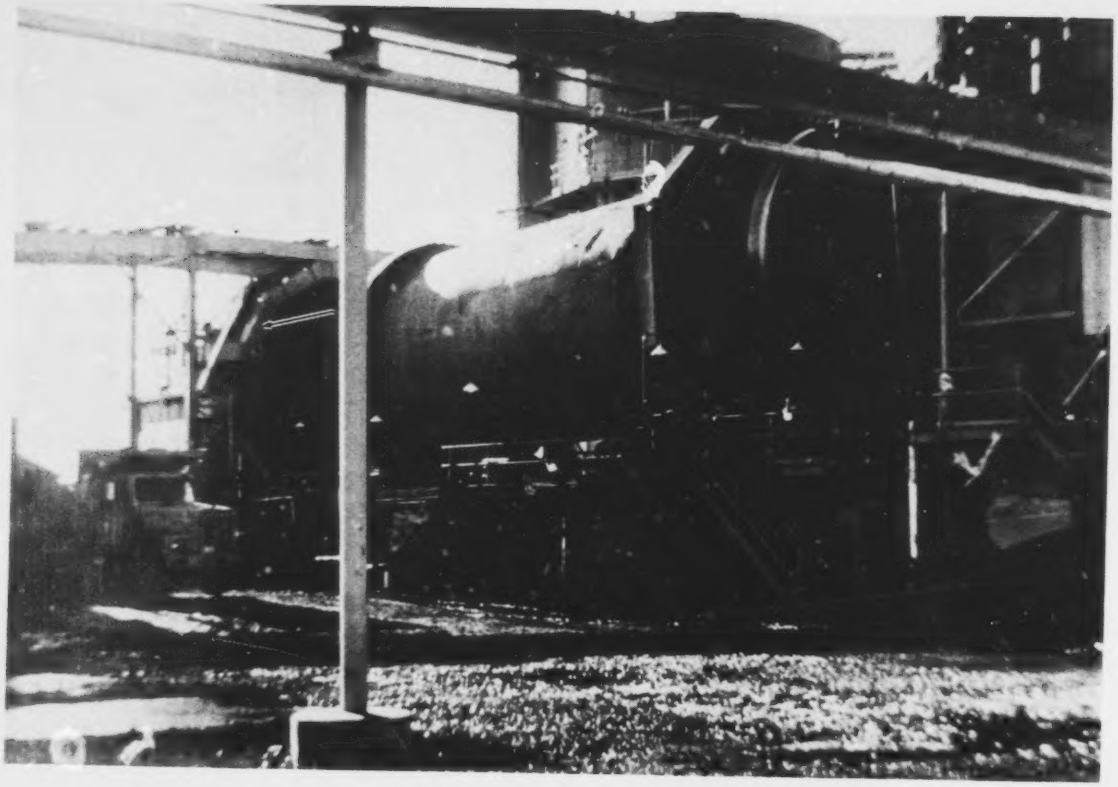


Figure 44. The Kiln.

Figure 45. Kiln discharge during standby operation.

TABLE 18. KILN REFRACTORY

Distance from feed end (m)	Refractory type type	Weight % fiber	Type of fiber
0 - 0.7	Coarse 26	3	304 *
0.7 - 6.2	Coarse 26	2	304 *
6.2 - 9.8	Coarse 26	0	---
9.8 - 17.1	Coarse 30	0	---
17.1 - 29.7	Coarse 30	2	330 *
29.7 - 30.5	Coarse 30	3	330 *

* Stainless steel

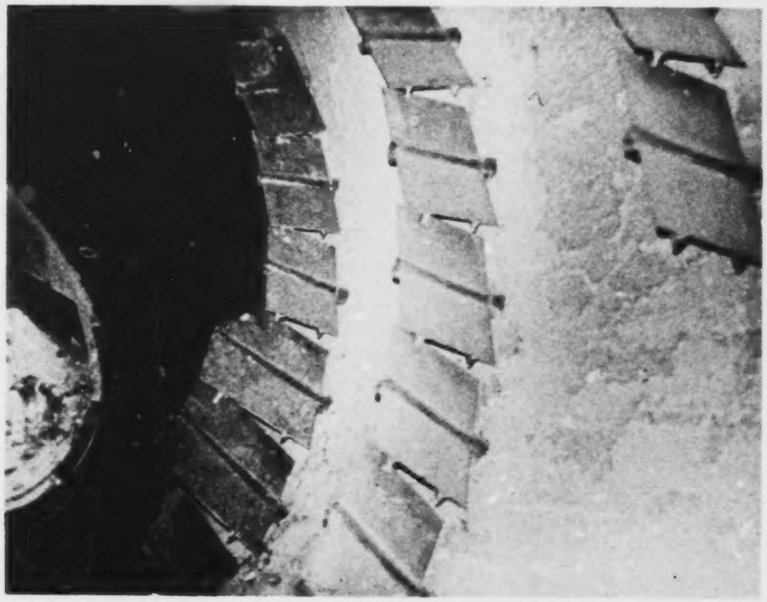


Figure 46. Kiln Flights.

As waste is extruded into the kiln, the flights are designed to move the refuse away from the feed area in order to minimize spillback into the seal tank below the feed hood. The flights are arranged in a helical pattern of six rows, each with twelve flights, spaced 1.3 m (51 in.) apart, the rows form a 60° angle with the longitudinal axis of the kiln. The rows begin 0.5 m (1.5 ft) from the feed end and extend 5.6 m (18.4 ft) down the kiln. Fabricated from 6-mm (0.25-in.) thick 330 stainless steel, each flight is welded to a 76-mm (3-in.) schedule 80 pipe. The pipe is welded to a pipe sleeve which in turn is welded to the kiln shell. While all plates are 76-cm (30-in.) long, those near the feed end are 40-cm (16-in.) high in order to pass under the ram snouts, and the rest are 60-cm (24-in.) high.

The spikes are designed to disperse the refuse so that more particles are exposed to the hot gases for the greater efficiency and higher rate of the processing reactions. The spikes are arranged in six longitudinal rows which are evenly spaced around the kiln circumference. Starting 6.3 m (21 ft) from the feed end and extending an additional 14.4 m (47 ft) down the kiln, each row has eight spikes with 1.8 m (6 ft) between the successive spikes. Fabricated from 330 stainless steel, each spike is 90-cm (36-in.) high. Like the flights, each spike is a 76-mm (3-in.) schedule 80 pipe welded to a pipe sleeve which in turn is welded to the kiln shell.

As shown in Figure 47, the rotary kiln is gear-driven by a 150-hp electric motor beneath the kiln midpoint. A water-cooled eddy current coupling (clutch) connects the drive motor to a variable-speed Falk gear reducer which in turn drives a pinion gear. The coupling is protected by a pressure switch that shuts down the drive system whenever the water pressure drops below a preset level. At the midpoint of the kiln bottom, the pinion gear meshes with a ring gear mounted around the kiln circumference. Enclosed in a sealed shroud to prevent rain from entering the gears, both gears are lubricated by a splash lubrication system.

The start-up sequence for the drive unit requires that the electric drive motor be up to operating speed before the clutch is engaged. Therefore, the kiln is equipped with a motor start/stop button, a speed control dial, a start/stop button for the eddy current clutch, and a jog run selector switch for the eddy current clutch. To start the kiln, the selector switch should be in the jog position. After the motor is started, the clutch is engaged by depressing the clutch start button. The speed control dial is then increased from 0 to the desired operating speed. When the kiln is up to speed, the selector switch is placed in the run position to complete the start-up sequence.

As a back-up power supply in the event of motor failure, the kiln has an air-cooled, 4-cylinder gasoline engine. This emergency drive system has a clutch power takeoff, a positive drive coupling, and an electric start.

The kiln is supported by two pairs of trunnions that maintain the kiln in position while allowing it to rotate. Each pair is approximately 7.6 m (25 ft) from the respective kiln ends with one trunnion in each pair being 30° to one side of the longitudinal line along the kiln bottom and the other trunnion being 30° to the other side (Figure 48). These trunnions

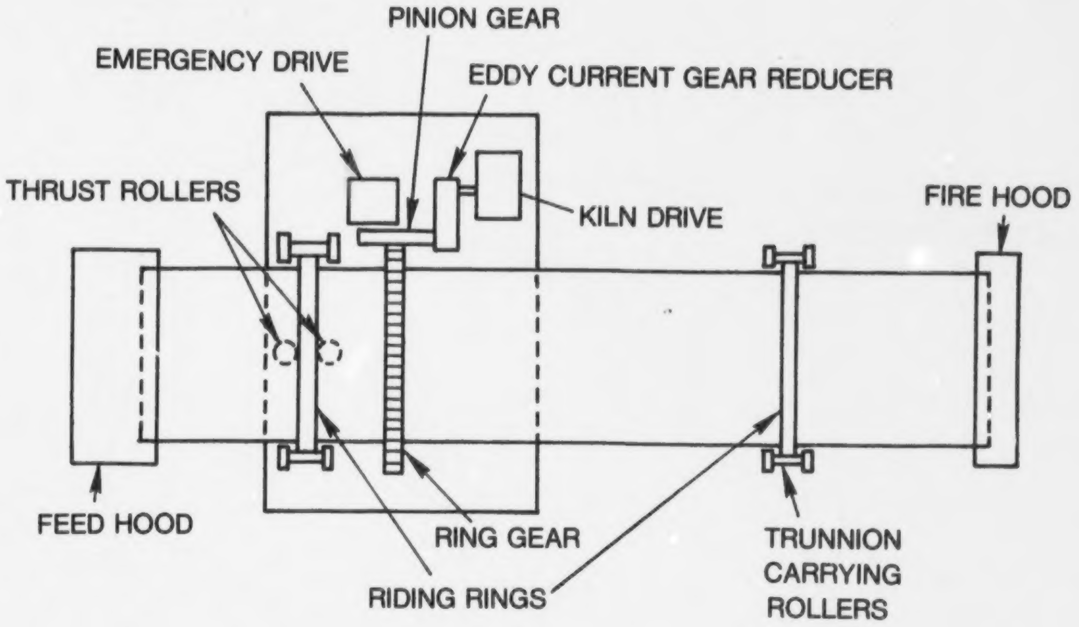

PINION GEAR
EMERGENCY DRIVE
EDDY CURRENT GEAR REDUCER
THRUST ROLLERS
KILN DRIVE
FIRE HOOD
FEED HOOD
RING GEAR
RIDING RINGS
TRUNNION CARRYING ROLLERS

Figure 47. Kiln auxiliary equipment.

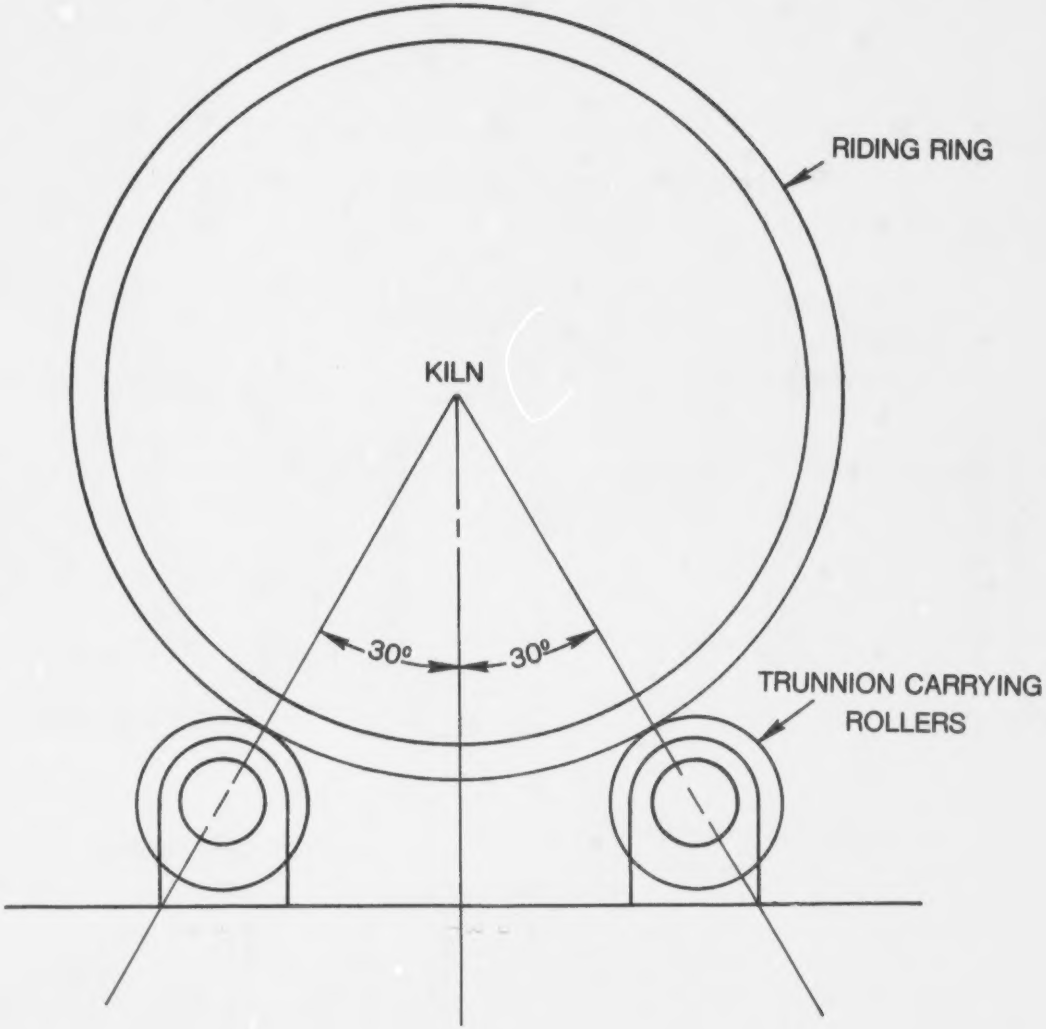

RIDING RING
KILN
30º
30º
TRUNNION CARRYING ROLLERS

Figure 48. Kiln Trunnions.

contact two bearing rings which extend around the circumference of the kiln. The rings slide around the kiln until the kiln shell expands at operating temperature to form a "shrink" fit. Each set of trunnion bearings has an oil bath lubricating system with cooling water tubes to maintain a constant temperature.

A Leeds & Northrup optical pyrometer monitors the temperature of the kiln refractory at the discharge end of the kiln. With a temperature range from 590° to 1260°C (1100° to 2300°F), the pyrometer is water-cooled to prevent heat damage from the high process temperature.

The negative pressure produced by the induced draft fan for the kiln process is maintained by the air-sealed hoods at each end, that is, the inlet or feed hood at one end and the discharge or fire hood at the other end. The air sealing for each hood consists of a water seal at the bottom and a triple-ply sheeting wrapped around the kiln at its junction with the hood. The sheeting is formed so that it presses against the kiln circumference when bolted to the hood. The three plies are two sheets of asbestos cloth with a rubber-coated woven brass fabric between them.

Fabricated from reinforced carbon steel and lined with 23-cm (9-in.) thick castable refractory, the feed hood is 2.7 m (9 ft) wide, 7.3 m (24 ft) long, and 8.6 m (28 ft) high. Its bottom water seal provides the means for discharging spillback and dust from the kiln onto a screw conveyor (which will be discussed later). On top of the hood is an emergency stack 2.4 m (8 ft) in diameter and 3.4 m (11 ft) in height. A counterbalanced lid on the stack is closed during normal operation and opened automatically when the power fails or the main induced draft fan stops to allow the escape of combustible gases. Operated by a pneumatic-powered cylinder under solenoid valve control, the lid is air-sealed by a water trough into which the lid fits.

Fabricated of the same materials as the feed hood, the fire hood has a rounded top and is 8.4 m (28 ft) long and 7.8 m (26 ft) high; its width increases uniformly from 1.2 m (4 ft) at the bottom to 1.4 m (5 ft) at the top. The hood is submerged 5 cm (2 in.) in the bottom water seal which provides the means for discharging the kiln processing residue ash, other inert solids, and some uncombusted char. In addition to an air inlet bustle, a sight port, and the optical pyrometer, the hood contains kiln combustion burners and air fans which will be discussed later.

As the shredded refuse tumbles down the kiln incline, it undergoes thermal processing in three zoned, but somewhat overlapping, stages where the temperatures progressively increase (Figure 49). The three stages are drying, pyrolysis, and combustion. In the drying process, an endothermic reaction, the heat is supplied by hot gases formed in the combustion stage. In the pyrolysis process, also an endothermic reaction with the heat similarly supplied by the hot gases from the combustion stage but at a higher temperature, the refuse is decomposed into combustible gases such as CO_2, CO, H_2, CH_4, and other hydrocarbons. In the combustion process, an exothermic reaction, carbon char and some pyrolytic gases are combusted to provide the

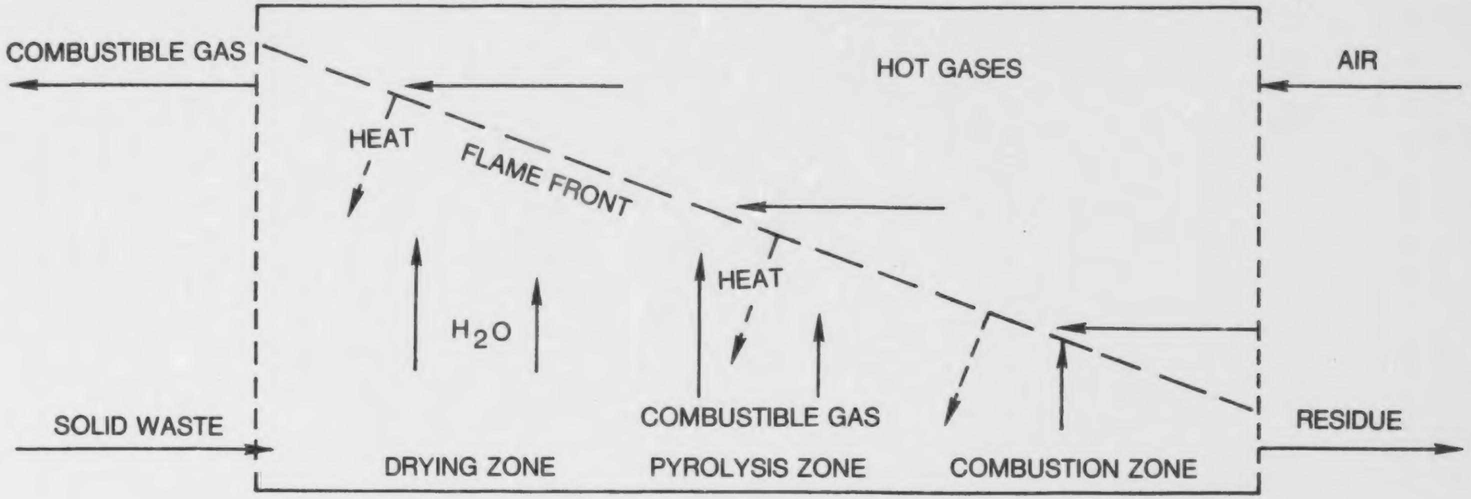

COMBUSTIBLE GAS
HOT GASES
AIR
HEAT
FLAME FRONT
HEAT
H_2O
SOLID WASTE
COMBUSTIBLE GAS
RESIDUE
DRYING ZONE
PYROLYSIS ZONE
COMBUSTION ZONE

Figure 49. Kiln processing zones.

heat for the endothermic drying and pyrolysis reactions and thus make the entire processing sequence self-sustaining. The three thermal processes are controlled by limiting the combustion air (supplied by the fans in the kiln feed hood) to a fraction of the stoichiometric requirement.

The main method of heat transfer in the kiln is radiation, but some convective heat transfer occurs between the refuse, the gases, and the refractory within the kiln. The description of the thermal processes occurring within the kiln are detailed in the kiln model (Appendix A).

Operating Experience

As verified by the low carbon monoxide and detectable oxygen levels in the kiln-off gas, the kiln functions more like a controlled air incinerator than as a pure pyrolytic reactor. However, the kiln operation as a substoichiometric pyrolysis reactor has two advantages over the typical incinerator operation. First, since the amount of air flowing through the kiln is limited with a consequent lesser turbulence and velocity of the gases, fewer solids are entrained in the kiln-off gas. Second, since the combustion air flows above rather than through the refuse bed, only small amounts of particulate are lofted into the kiln-off gas stream. While a low-energy scrubber could theoretically remove the particulate to comply with emission standards, some metals in the refuse are reduced and vaporized in the kiln because of the reducing conditions. This metal vapor is later oxidized in the gas purifier which produces a condensation aerosol (similar to those formed in incinerators) that is difficult to remove from the discharge gases.

To complete the waste burnout while preventing the formation of slag clinkers requires continuous regulation of the process control parameters because of the variation in refuse mass rate, moisture content, and composition. The three basic process control parameters are the combustion air supply rate, the kiln rotational speed, and the supplementary fuel rate.

The regulation of the combustion air supply controls the amount of pyrolysis gas and carbon char combusted and in turn the amount of heat released and supplied to the drying and pyrolysis reactions. The air supply regulation, therefore, is the primary means of controlling the reaction rates of the three thermal processes.

As the kiln speed is increased or decreased, the retention time and agitation of the refuse are proportionately more or less and, consequently, the temperature and processing rate of the refuse are changed accordingly.

The kiln speed is varied primarily to provide fast response conditions for the alleviation of crisis situations such as when large slag balls are being formed during process upsets (Figure 50).

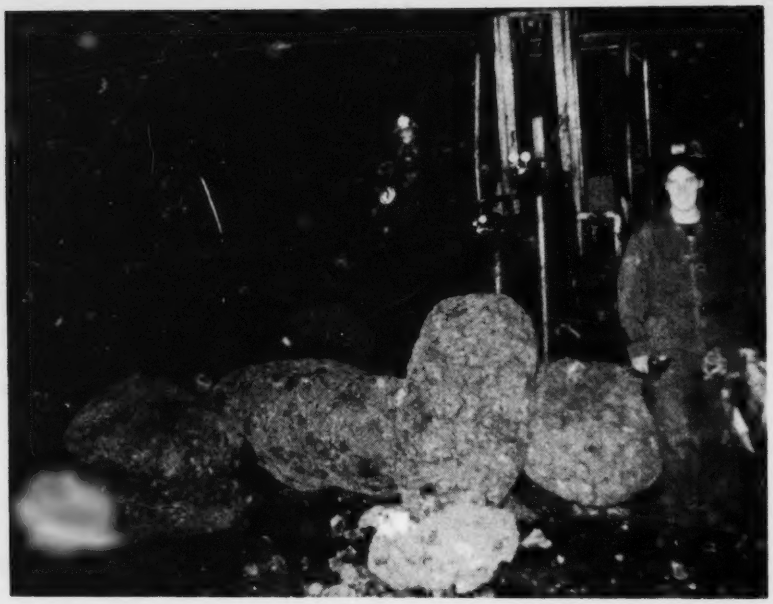


Figure 50. Kiln residue slag balls.

The processing heat can also be controlled by regulating the rate of the supplemental fuel oil injected into the kiln. Such control, however, is used only when other controls are not successful. Usually, supplemental fuel is used during the kiln heat up before normal thermal processing of refuse and during normal thermal processing to fire only the main kiln burner and the safety burners. The safety burners were installed to prevent explosive gas accumulations.

To ensure the proper and thorough thermal processing requires monitoring the process performance indicators and accordingly adjusting the process control parameters. A major indicator of proper process control is the degree of residue burnout (residue quality). This is particularly important since it affects the operation of the residue separation module. The operation of this module, however, has been suspended indefinitely. When the refuse is properly processed, there is a maximum heat release for thermal recovery, a minimum putrescible content for landfill disposal, and a minimum accumulation of unburned waste floating on the surface of the residue quench tank. When the refuse is overly processed, the refuse tends to fuse into large slag balls. Since these balls (sometimes larger than 1 m, 3 ft) will not pass through the residue bypass and may damage the residue tank conveyor, they must be removed from the conveyor by a mobile crane. Currently, the residue quality is monitored visually by a man stationed in the residue discharge area.

The optical pyrometer was intended to sense the ash temperature so that a low temperature would indicate a refuse underprocessing and a high temperature would indicate a refuse overprocessing and conditions for likely slag ball formation. However, when the pyrometer was originally placed in the fire hood opposite the point where ash discharges from the kiln and focused on the ash, it could not give valid measurements because of particles lofted into the gas stream and slag accumulating on the lens. After the pyrometer was moved to the opposite side of the hood and focused on the kiln refractory lining, it operated satisfactorily. The pyrometer was replaced once because of heat damage sustained when the cooling water to the pyrometer stopped flowing.

As another important indicator for regulating the process control parameters, the O_2-CO_2 analyzers were intended to monitor the composition of the kiln off-gas thereby indicating the amount of excess air in the kiln. The analyzer has a water-cooled probe which is inserted into the hot gas duct and an aspirator for extracting the gas sample. While the analyzer has a much faster response to process changes than the temperature indicators, it has never functioned properly because of the continuous failure of its water-cooled probe.

Early in the demonstration, considerable kiln operational difficulties occurred. While the kiln was designed for plug flow (Figure 49), a vortex gas flow (Figure 51 developed in the pyrolysis and combustion zones. This vortex allowed pyrolytic gases to flow to the combustion zone where they were mixed with air and combusted resulting in extremely high temperatures and, subsequently, slagging of the residue. It is also possible that a pyrolytic gas and air mixture developed within this vortex and exploded causing the large pressure pulses observed early in the demonstration.

To rectify this situation, an air distribution bustle was installed around the circumference of the kiln at the discharge end. Combustion air which originally entered the kiln as a concentrated steam is now distributed around the circumference of the kiln. This modification has improved the kiln operation considerably and also has a beneficial cooling effect on the shell and refractory at the discharge end of the kiln.

During the plant shakedown, the kiln had numerous operational deficiencies related to the integrity of the kiln refractory, the strength of the flights and spikes, and the effects of high temperature on the kiln shell. To whatever extent, faulty installation, improper material specification, and process instabilities all contributed to the kiln failure to perform as designed.

Supplied by General Refractory, the original kiln refractory was a low-temperature type for the first 23 m (75 ft) beginning at the feed end and a high-temperature type for the last 8 m (25 ft) extending to the fire end. Before any waste was fired some refractory spalled off and after only a bald spot developed. Since the spalling was due to improper installation, the contractors agreed to a financial settlement. After refuse was fired,

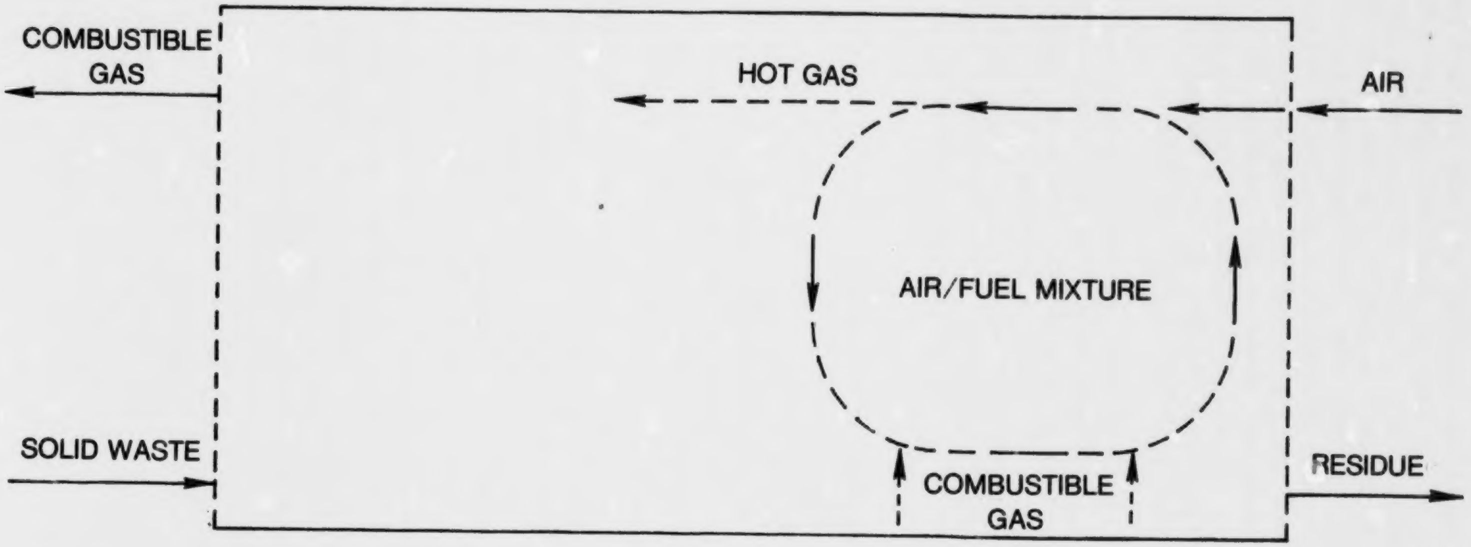

COMBUSTIBLE GAS
HOT GAS
AIR
AIR/FUEL MIXTURE
SOLID WASTE
RESIDUE
COMBUSTIBLE GAS

Figure 51. Vortex gas flow in the kiln.

other refractory disintegrations were due to ram snout failures that allowed cooling water to thermally shock and shatter the hot refractory. Consequently, the first 8 m (25 ft) of the refractory from the feed end was replaced with an A. P. Green coarse aggregate refractory. As detailed later, the last meter (3 ft) of refractory at the fire end fell out because of the kiln shell expansion at the high process temperatures. Although unsuccessful, segmented castably refractory with floating anchors was tested in several configurations to repair this fallout

Holes in the refractory for the flights and spikes provided breaks in the refractory structure which widened whenever a flight or spike was removed. Since the patches to fill these holes as well as those to repair other areas continually fell out, the entire kiln lining was replaced with the presently installed monolithic layer of refractory.

After 6 months of operation and many temperature cycles, the new refractory was in good condition. Although there were minor cracks, no large pieces of refractory had fallen out.

Most of the current refractory loss is due to spalling, particularly during the heat-up and cool-down cycle when the different coefficients of expansion and contraction for the slag and refractory have the greatest effect. When the slag and refractory cool off and the slag adheres firmly to the refractory, the slag with its greater contraction cracks. Then, when the kiln is rotated during the next heat up, the brittle slag breaks off with a portion of the attached refractory.

The original kiln shell was fabricated of mild steel with 46 cm (18 in.) on each end of the kiln made of 310 stainless steel. Since stainless steel has a larger coefficient of expansion than mild steel, the kiln ends expanded into a conical shape (Figure 52) when the kiln was hot. During one run, the shell so expanded away from the refractory that about a meter of refractory at the fire end fell out. This refractory was not replaced on the assumption that the slag buildup would provide sufficient protection for the shell. However, the kiln was so badly damaged during this run that the first 5 m (16 ft) of the shell had to be replaced. To provide for the shell expansion, the replacement was made of mild steel and the ends of the kiln shell were slotted (Figure 52).

When the kiln was relined, the original 310 stainless steel spikes were replaced with 330 stainless steel pipes. After 6 months of operation, the spike deterioration was negligible except for some spikes that were bent by a large slag ball rolling down the kiln.

Originally, the flights were constructed of 310 stainless steel and each consisted of a plate welded to two posts. Also the original flight arrangement was four rows of flights on the quarter points with the rows extending axially from the feed end to 2 m (6 ft) beyond the ram snouts, or 4.5 m (15 ft) down the kiln. Although this configuration allowed considerable amounts of refuse spillback, the spillback increased to an unacceptable level when the flights were temporarily removed. Consequently, two alternate flight designs were tested--one being a sliding plate supported by two posts

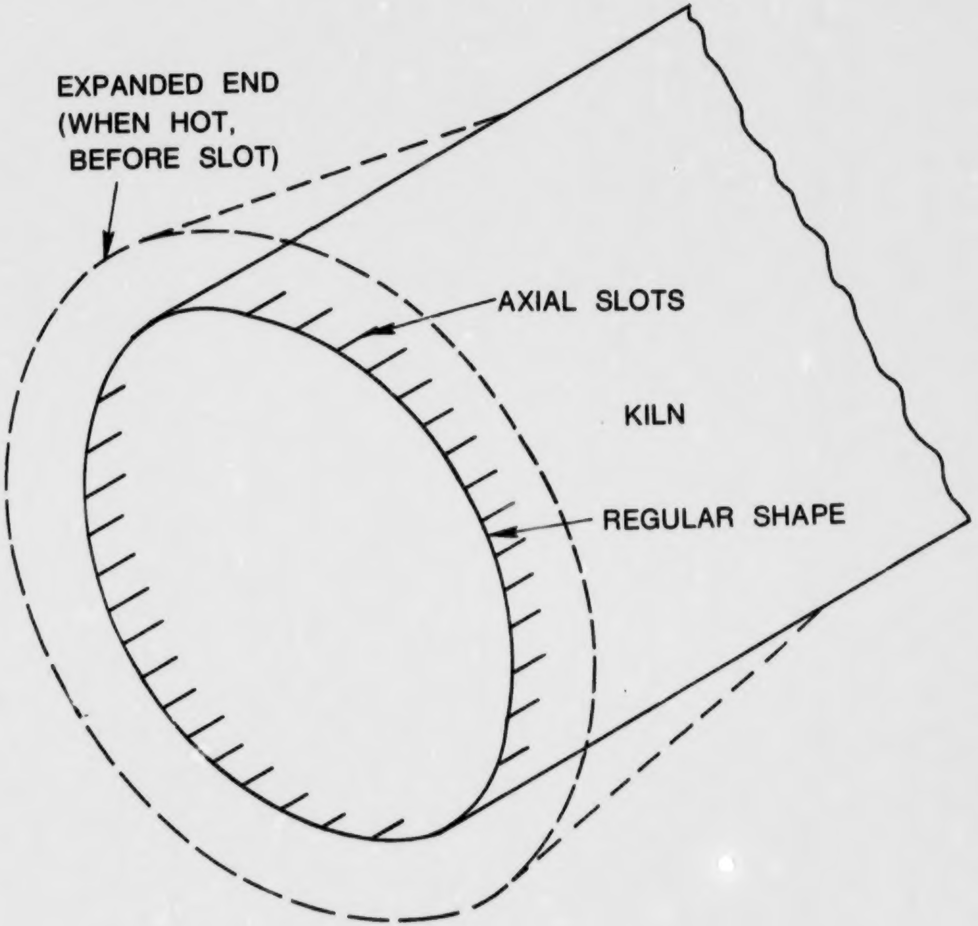

EXPANDED END
(WHEN HOT,
BEFORE SLOT)
AXIAL SLOTS
KILN
REGULAR SHAPE

Figure 52. Conical expansion of kiln ends and corrective slots.

and the second, which was selected, being a plate welded to a single post. In addition, the 4-row configuration was changed to the present 6-row helical pattern. Moreover, the construction material for the flights was changed from 310 stainless steel to 316 stainless steel and finally to 330 stainless steel. After six months of operation, the current flights showed negligible deterioration.

During the shakedown, a new motor had to be installed in the electric drive system. The dynamic coupling in the system has frequently overheated when unusually low ambient temperatures have frozen the cooling water lines to the coupling. Since the coupling overheating also interferes with the feedback signal from the kiln drive, the speed controller does not sense any kiln rotation, resulting in the controller excessively increasing rotational speeds of the kiln.

The start-up of the kiln rotation has been difficult when slag buildup has inbalanced the shell. It has also been aggravated when the start-up procedures, such as jogging the drive and bringing the motor up to speed, are not performed in the proper sequence described previously.

Continuously leaking of lubricating oil from the kiln ring gear required three separate gear modifications, including replacement of the rain shield over the drive gear, before the leak was finally stopped.

To ensure the capability of starting the kiln emergency drive, the drive was originally equipped with a hand crank starter. However, this manual starter was replaced with an electric one after many personal injuries had been sustained during the cranking.

The kiln trunnions must be kept in nearly perfect alignment to prevent excessive wear or overheating. Metal flaking off the trunnions and the ring supports is a potential cause of equipment malfunctions. Graphite flakes have proved to be more effective than powder in lubricating the ring supports. During extremely cold weather, particularly when the system is cool and water has not been drained from the system piping, the freezing of the cooling coils for the trunnion lubrication bath has caused valves, couplings, and pipes to break. To ensure effective operation when the system is hot, the lubrication system for each trunnion is shielded from the heat radiated from the processing kiln and gas purifier.

The kiln stack lid was originally lined with castable refractory. However, after the refractory deterioration had caused a lid imbalance which in turn impeded the automatic system capability of opening the lid as required, the refractory was successfully replaced with a blanket insulation held by wire mesh. As a result of the exposure of the stack lid to severe heat and flame when it is opened, the lid has become warped and the insulation lining has fallen out twice. To maintain a seal with the warped lid, the level of water in the seal trough at the top of the stack had to be raised. When the lid opens, the escaping hot gases burn and damage nearby wires and other equipment because of the low profile of the stack above the feed hood.

For various reasons, the emergency stack lid has failed to open or has been difficult to open. When the induced-draft fan has an emergency shutdown and the stack lid fails to open, combustion gases accumulating in the kiln produce a positive pressure. This positive pressure forces hot gases into the ram tubes where the refuse ignites and the fire spreads to the ram feed hoppers where it subsequently damages the rubber belt and the head pulley of the kiln feed conveyor. In one instance, when a power surge overloaded the equipment protection circuits, all the system equipment was shut off. Although the induced draft was off, which requires that the emergency system be activated, the air compressor which supplies the pneumatic force for the lid opening was also off. Consequently, the kiln feed conveyor was so badly damaged that refuse could not be processed for two days. This system would work much better if the stack lid was designed to open by gravity when the pressure was relieved from the cylinder.

The feed hood has had very few operational deficiencies. Although large slag deposits accumulate in the hood, they have not adversely affected the refuse processing or the integrity of the refractory lining. However, when refuse is being processed, the hood view ports serve little value since the flames within the hood completely obscure the vision of the hood interior.

During the early stages of the demonstration period, pressure pulses within the kiln caused the fire hood to vibrate so severely that it had to be structurally reinforced. In addition, since the refractory brick in the fire hood is not water resistant, all bricks wetted by the residue quench water have deteriorated.

Originally, the circumferential shell-hood junction at each end of the kiln was enclosed by a steel labyrinth seal. However, because of the insufficient clearance to allow for the thermal expansion while not restricting the kiln rotation, the original seals were replaced with the triple-ply sheeting of rubber coated woven brass fabric within two sheets of asbestos cloth. The present seals, however, must be replaced six times a year because of the damage sustained by the blowback of process gases, excessive heat, and wear. Moreover, the replacement is excessively time-consuming and can be made only when the system is cool. To minimize such damage and the resultant downtime, a properly designed steel labyrinth could serve as a protective base for the triple-ply seal.

The kiln has generally proven satisfactory for refuse handling and thermal processing. While the refractory deficiencies have apparently been remedied, desirable improvements would include better process control for greater system stability, more effective gas temperature measurement and gas composition analysis techniques and instruments, more extensive use of automatic system controls, and closer operator monitoring of the entire processing. Many of the kiln operational deficiencies will be discussed later in the problem analysis volume of this report.

Maintenance

After the modifications prompted by the demonstration experience, most of the emergency maintenance in the kiln has been limited to trunnion malfunctions because of freezing in the water-cooling coils. Except for the replacement of the shell-hood junction seals, the other routine maintenance requirements, namely those for repairing the kiln lining, aligning the kiln, lubricating the moving components, and checking the electrical system, have required normal time and effort. The preventive maintenance schedules for the kiln and the kiln feed hood are shown in Tables 19 and 20 respectively. The kiln fire hood preventive maintenance consists of zeroing, calibrating, and checking the operation of the pressure indicator annually.

Gas Purifier

The kiln-off gases collecting in the feed hood are discharged through the crossover duct into the gas purifier (see Figures 53 and 54). With provisions for gas mixing and retention, the gas purifier, functioning basically as an afterburner for the kiln-off gases, serves the two-fold purpose of combusting all inflammable gases and of removing particulate from the gas stream by a cyclonic action. The combusted gases are air-quenched before being discharged to the boilers for energy recovery. The particulate flows as liquid slag into a taphole where it falls into a water quench within a seal tank below the gas purifier where it is removed by a screw conveyor.

Description

The gas purifier is a horizontal, cylindrical, carbon-steel shell sloped 4 percent toward the inlet end where the slag taphole is located directly beneath the inlet port (Figure 54). Lined with a ring of high-temperature, 23-cm (9-in.) thick alumina brick refractory, the shell is 16 m (0.625 in.) thick, 5.5 m (18 ft) in diameter, and 15 m (50 ft) long, and has a tangential inlet and an axial outlet. The gas purifier originally had two semicircular baffle walls installed perpendicular to the longitudinal axis of the vessel, one at the top of the vessel and the other at the bottom of the vessel. The upper and lower walls were 5 and 7 m (16 and 23 ft) respectively, downstream from the inlet, and the lower wall had a hole in its base to allow slag to flow under it. The slag taphole was originally 1.4 m (4.5 ft) wide and 2 m (6 ft) long. Directly beneath the slag taphole is the slag quench which, as part of the seal tank, will be discussed later.

The tangential inlet is formed by the crossover duct which connects the kiln feed hood to the gas purifier. The duct, 2.1 m (7 ft) in diameter, is lined with castable refractory 115 mm (4.5 in.) thick. Both the kiln off-gas combustion fan and the dust collection fan discharge into the crossover duct.

TABLE 19. KILN PREVENTIVE MAINTENANCE SCHEDULE

Daily

Check all moving parts for lubrication.
Check water flow to trunnion bearings and couplings.
Lubricate the kiln helical girth gear and pinion through the inspection door of the gear guard (Gulf EP115).
Be sure the supply of graphite slabs is ample to lubricate the tire for one day.
Check and adjust if necessary the distance "x" on each carrying roller assembly.
Observe the position of the trust tire with respect to the two thrust rollers and adjust the carrying bearing slightly to "FLOAT" the kiln.
Check lubrication:
  Carry roller bearings (EP5).
  Gasoline engine (Super HDX20).

Weekly

Check emergency kiln drive:
  Easily started.
  Antifreeze during freezing weather.
Check the lubrication of helical ring gear and position (Gulf EP115).
Grease emergency drive shaft bearings (LiEP2).
Check drive reducer oil level.
(Winter - Paradene X1000)
(Summer - Paradene X1500)

Monthly

Grease thrust roller bearings (LiEP2).
Check emergency drive speed reducer oil levels.
(Winter - Paradene X1000)
(Summer - Paradene X1500)
Lubricate jaw coupling with open gear (800).

Quarterly

Grease drive shaft couplings and outboard bearings pinion shaft (LiEP2).
Apply molycote to tires.

CONTINUED

TABLE 19. (Continued)

Semiannually

Complete inspection.
Check reducers.
Check oil in emergency drive engine (Super HDX20).
Change oil in auxiliary drive Falk speed reducer.
(Winter - Paradene X1000)
(Summer - Paradene X1500)
Change carry roller bearing roller lube (EP5).
Change oil in helical ring and pinion gear (Gulf EP115).
Lubricate output shaft spider under coupling guard at dynamatic and at electric motor (LiEP2).
Check motor, alarm, interlock, speed tachometer, and speed indicator alignment.

Alignment

Megger motor.

TABLE 20. KILN FEED HOOD PREVENTIVE MAINTENANCE SCHEDULE

Annually

Check operation of solenoid valve.
Check air supply pressure.
Check condition of pneumatic cylinder.
Check operation of electrical system.
Zero and calibrate feed hood off gas temperature indicator controller.
Zero and calibrate millivolt to current converter.
Check condition of thermocouple.
Zero, calibrate, and check operation of pressure indicator.

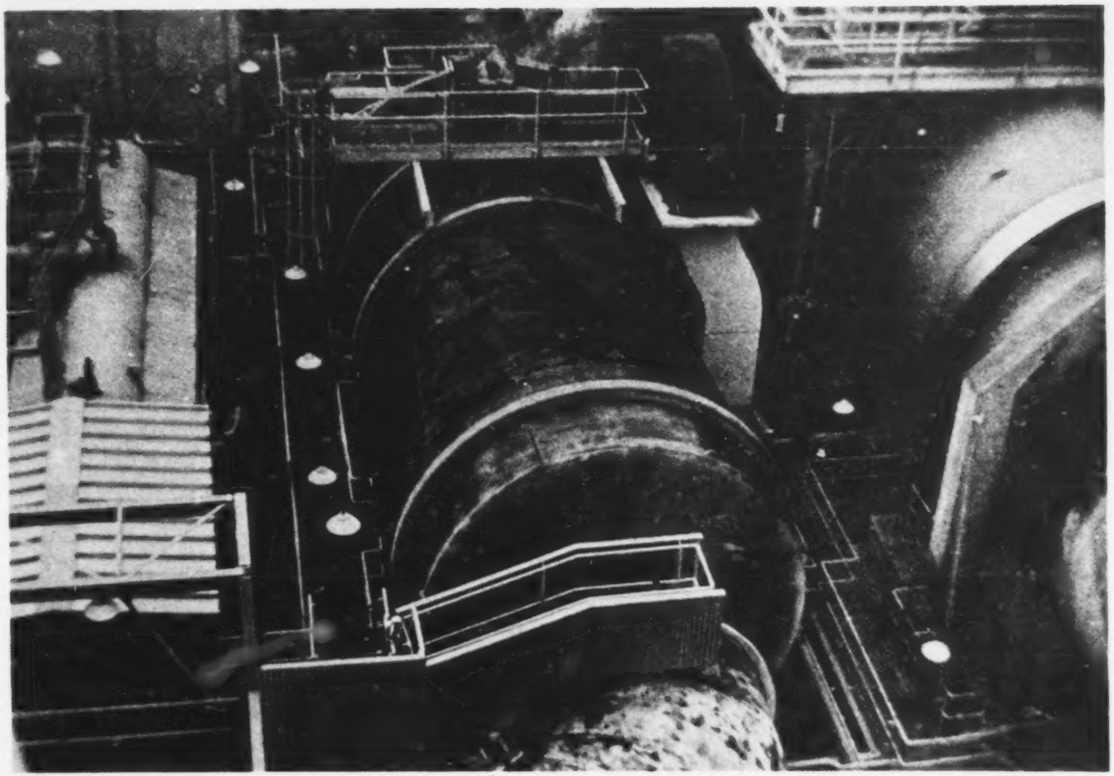


Figure 53. Gas Purifier.

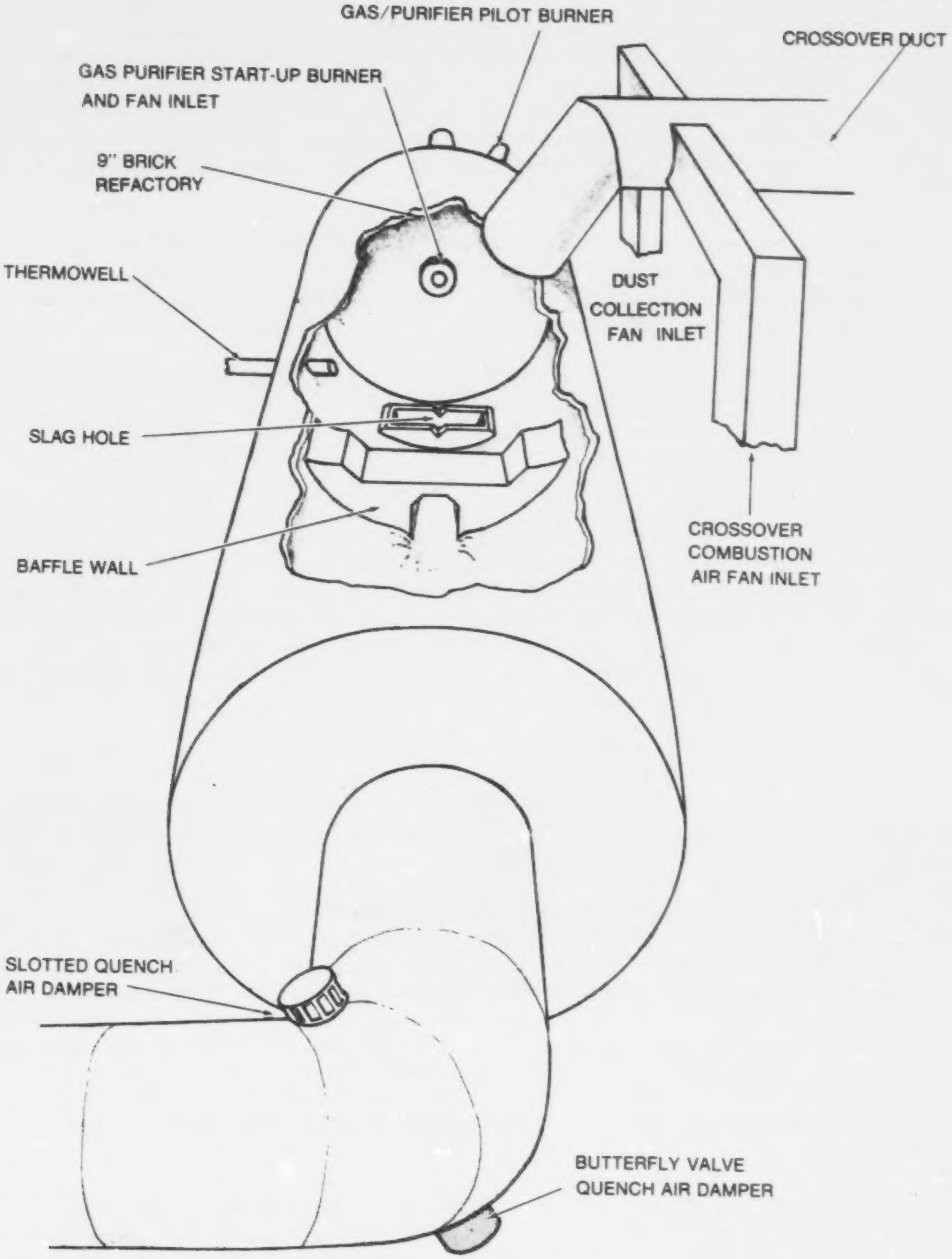

GAS/PURIFIER PILOT BURNER
CROSSOVER DUCT
GAS PURIFIER START-UP BURNER AND FAN INLET
9" BRICK REFACTORY
THERMOWELL
DUST COLLECTION FAN INLET
SLAG HOLE
CROSSOVER COMBUSTION AIR FAN INLET
BAFFLE WALL
SLOTTED QUENCH AIR DAMPER
BUTTERFLY VALVE QUENCH AIR DAMPER

Figure 54. Schematic of the gas purifier.

The axial outlet for the gas purifier has an inside diameter of 3 m (10 ft) and is sloped toward the inlet end to allow molten slag to flow toward the slag hole. The outlet is refractory-lined with high-temperature alumina brick 23 cm (9 in.) thick. A sample port for the CO_2 analyzer is in the top of the outlet duct. The outlet duct makes a 90° horizontal turn 3 m (10 ft) downstream of the gas purifier and connects to the refractory-lined horizontal duct work to the boiler inlets. Two quench air dampers on the 90° elbow will be detailed later.

Two thermocouples project from the vessel side into the gas stream, one midway and the other three-fourths of the way down the vessel length. These thermocouples are enclosed in ceramic thermowells to protect them from the high temperature and the corrosiveness of the process gas.

There are two sight ports for observing the slag hole, one directly above the hole and the other in the vessel disc at the inlet end.

Operating Experience

Air from the dust collection and kiln off-gas combustion fans is mixed with kiln off-gases in the crossover duct. As the mixture enters the gas purifier, it is ignited by a pilot burner in the gas purifier. With the entrained particulate maintained in a fluid state by temperatures of about 1300,C (2350,F), the combined tangential and gravitational forces throw the fluid particulate to the walls. Then as molten slag, the removed particulate flows down the sloped floor to the slag taphole and falls into the water quench where it becomes frit.

When the flow rate and composition of the kiln-off gas vary, the combustion air input must be delicately controlled to maintain the process temperatures. The amount of excess air supplied for the combustion reaction can be automatically or manually controlled to produce temperatures high enough for the particulate maintenance in the fluid state, the most important condition in the gas purifier operation. However, to produce such temperatures requires operating near the peak of the stoichiometric curve with little or no excess air because of the low heating value of the kiln-off gas. Such operation is somewhat unstable since a low temperature could indicate either too much excess air or insufficient combustion air for heat release. Consequently, it is difficult to control the temperature automatically. Moreover, since the air combustion is usually not completed because of the limited excess air, some carbon monoxide and hydrocarbons escape in the exit gas. Fuel oil is added to maintain the process temperature only when little or no waste is being fed to the kiln and, consequently, less kiln-off gas is being produced.

The amount of excess air in the gas purifier cannot be determined reliably since the CO_2 analyzer, similar to the unit for the kiln, has functioned sporadically. Consequently, other indicators of the gas purifier performance have become more important in the monitoring needed to adequately control the processing in the gas purifier.

Since the kiln-off gas supplied to the gas purifier collects in the kiln feed hood, the operational characteristics of the gas purifier can be anticipated by monitoring the kiln. If the kiln is underprocessing the refuse, the heating value of the kiln-off gas entering the gas purifier will be very low. If the temperature is high, air has probably leaked through the air seal at the ram feeders and combusted much of the pyrolytic gas in the feed hood; therefore, the amount of combustible gas normally flowing to the gas purifier will be severely depleted. In any event, the temperature measured by the two thermocouples in the gas purifier is the primary indicator of the gas purifier operation. Another important indicator is the condition of the molten slag flow down the vessel walls and into the slag taphole as observed through the view ports in the gas purifier.

The gas purifier was designed for a maximum temperature of 1540°C (2800°F) and an average temperature of 1100°C (2000°F). However, to maintain a fluid slag, the average operating temperature was increased to 1370°C (2500°F) with some temperatures exceeding 1650°C (3000°F), the maximum temperature of the thermocouple recorders. Consequently, the thermocouples failed, and the high temperatures were the primary cause of failure of the refractory in the gas purifier.

The design gas residence time in the gas purifier was 1.25 seconds, but because of the higher temperature and mass flow rates, the actual operating residence was reduced to 0.85 second. Although the reduced time limited the degree of vessel combustion, it increased the amount of particulate removed because of the greater intensity of the cyclonic flow.

During the demonstration period, the slag taphole frequently became clogged with solidified slag that had chilled because of temperature fluctuations during irratic operations. When operating, the vessel is filled with flames that obscure vision of the hole. The feeding of refuse to the kiln had to be interrupted daily for 15 minutes to determine the hole status. However, since this procedure increases the temperature fluctuations and therefore the conditions for slag chilling and clogging, an alternative method should be developed for the hole monitoring.

The baffle walls were designed to make the temperature profile in the gas purifier more uniform by forcing the stream of particulate-laden gas to change directions. As described above, the original system had two semicircular walls separated by 2 m (6 ft) with one wall at the top and the other at the bottom of the vessel surface to force the gas stream down and then up. After the original walls were damaged, they were replaced by a single donut-shaped 50-cm (20-in.) thick wall with a 3 m-(10-ft) diameter orifice in the wall center (Figure 55). Built with Charles Taylor Tamul refractory brick, the new wall had an operational life of about 50 days. Although most of the bricks had separated and fallen because of the slag chemical effects which had deteriorated the bricks and etched out the mortar between them (Figure 56), the bottom section of the wall remained intact until the gas purifier was relined (Figure 57).

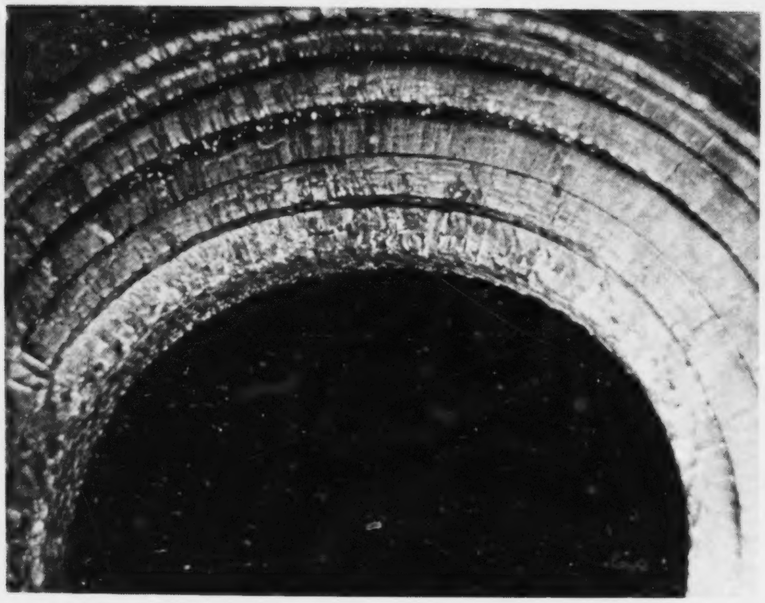


Figure 55. Orifice baffle wall in the gas purifier.

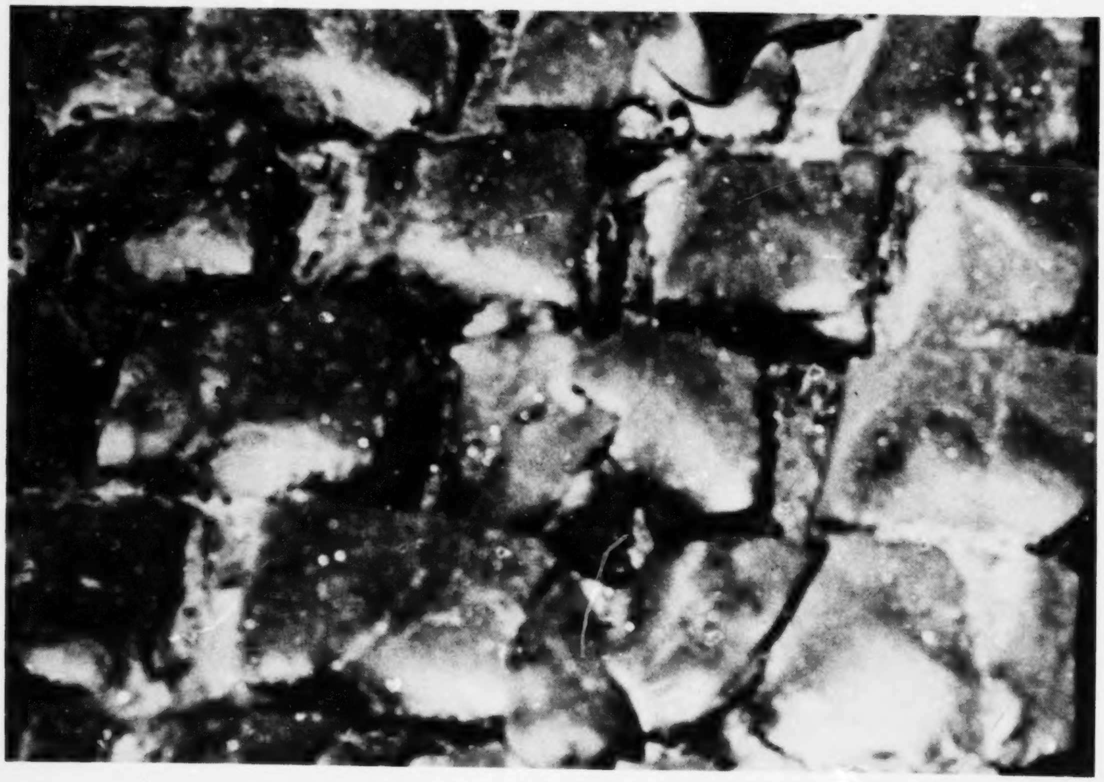


Figure 56. Deteriorated refractory and etched mortar in the gas purifier.

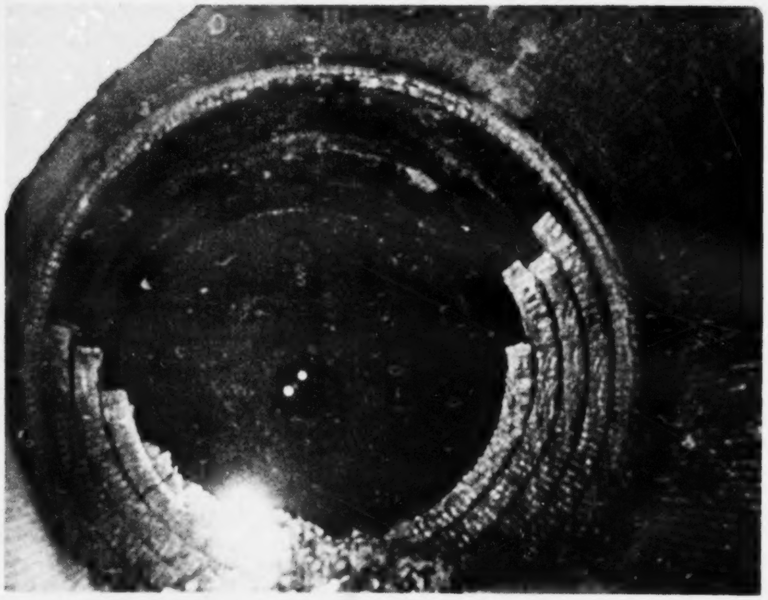


Figure 57. Fallen orifice baffle wall in the gas purifier.

The operational life of the thermocouples inserted into the gas purifier was only 7 to 10 days because of the high temperatures and the chemical effects of the gas and slag. Many thermowell shields tested to protect the thermocouples failed in a short time.

Initially, the slag flowed slowly in a thin film over the edge of the slag taphole exposing a large surface area of the slag for possible heat loss. While the solidification of the slag in the slag taphole could have numerous causes, two possible causes were low slag hole temperatures due to radiant heat loss to the quench water or the cooling effect of the relatively cool steam evaporated from the quench water in the seal tank. To prevent the solidifying, an oil burner was installed in the hole to elevate the temperature. However, the long, narrow burner flame impinging on the hole wall damaged the refractory and burner combustion air entering the hole cooled and solidified the slag when the burner was not firing. Consequently, the burner was removed.

After the failure of the burner to minimize the slag solidifying the next efforts were intended to reduce the heat loss from the hole area and to modify the conditions leading to slag solidfying. To this end, the size of the slag hole was reduced and a cantilevered edge was built around the hole so that the slag would fall more sharply into the hole. Also insulation and a smooth lip made of A. P. Green 88P refractory were installed in the hole, and a dam with a V-notch weir on two sides constructed of A. P. Green 90P refractory was installed around the hole (Figure 58). The dam and weirs were designed to so converge the slag flow so that a smaller slag area would be in contact with the cooling surfaces. Since the slag continued solidifying over the hole, the dam height on the sides of the kiln crossover duct was doubled to form a gas flow screen that would minimize particulate impingement on the opposite side of the hole. The operational life of the dam is limited to about 80 days because of erosion and the slag and gas chemical effects.

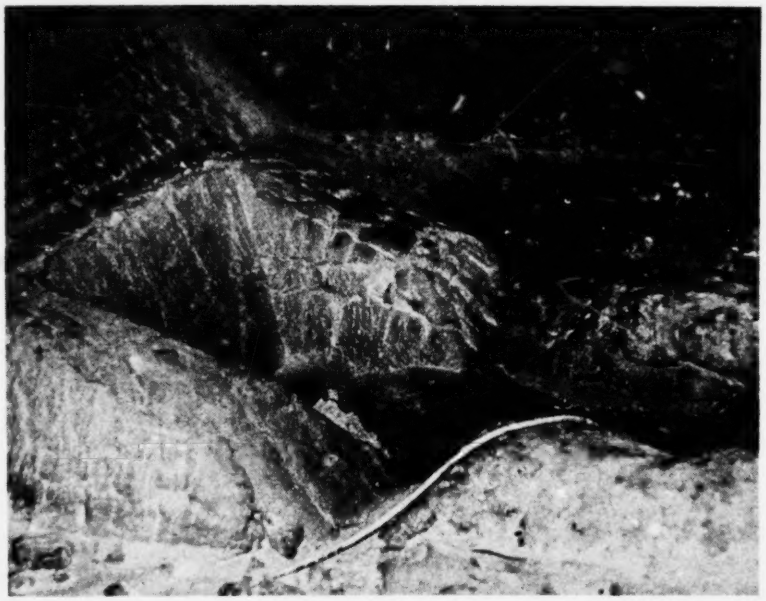


Figure 58. Slag taphole dam with V-notch weirs.

After the foregoing modifications also failed to prevent the slag hole plugging (Figure 59), two propane burners were installed on the slag hole sidewall, 90° to the right of the original burner position, and the original oil burner was reinstalled. Although expensive, the propane burners have good flame patterns for the hole application. After sustaining damage from the high radiant heat in the gas purifier, these burners were shielded by corrugated sheet metal. Before the oil burner was reinstalled, its air and fuel pressures were modified to produce a bushy flame pattern. While the oil burner was much more effective then before, the propane burners were still needed intermittently to prevent the slag from plugging the hole.

With the mortar deteriorating more rapidly than the brick, the vessel refractory lining thickness decreased about 1 mm (0.04 in.) each operational day. Consequently, the refractory in the gas purifier has a very short life. Moreover, the rising skin temperatures of the vessel as the refractory thickness decreases threaten the structural integrity of the vessel. When skin temperatures as high as 370°C (700°F) were measured, the entire vessel was water-cooled to protect it from thermal damage.

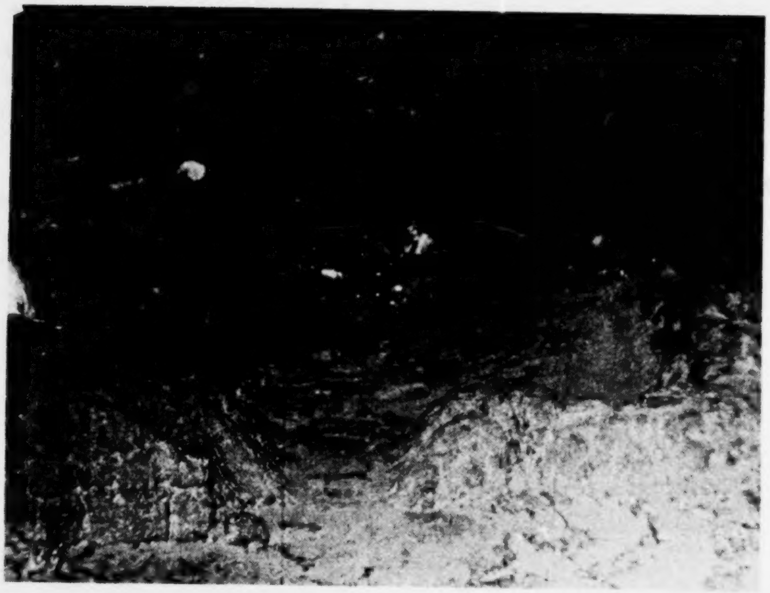


Figure 59. Plugged slag taphole.

The saddle supports for the vessel could not maintain the proper alignment for the gas purifier because of the extreme vessel expansion and contraction. These thermal changes also caused a foundation pillar to crack.

Originally, the dust collection fan discharged into the crossover combustion air fan which in turn discharged into the crossover duct. Since the flow and pressure characteristics of the crossover combustion air fan were such that excessive pressure pulses were produced in the kiln, the fan configuration was modified so that the dust collection fan discharged directly into the crossover duct, and, as recommended by Monsanto, the duct for the crossover combustion air fan was reduced to one-third of its original size. In addition to improving the gas mixing, these modifications helped to equalize the temperatures in the gas purifier. To further reduce the pressure pulses, a lattice wall was installed in the crossover duct. However, when this wall proved to be of little value and became filled with slag, and it was subsequently removed.

Many refractory failures occurred in the area where the crossover duct enters the gas purifier because of the intense erosion due to the directional change of the gas stream in this area and the high temperature due to this area being immediately downstream of the combustion air inlets.

Before the gas purifier performance can be considered satisfactory, the slag hole plugging must be further reduced and the refractory lining must be redesigned to minimize its current excessive deterioration.

Maintenance

Although the gas purifier required little routine maintenance (Table 21) since it has no moving parts, the thermocouples and thermowells must be replaced frequently, and the slag hole plugging must be checked and cleared continually. The refractory repair and replacement continue to be the major maintenance requirement.

TABLE 21. GAS PURIFIER PREVENTIVE MAINTENANCE SCHEDULE

Annually

Zero and calibrate:
  Temperature indicating controller.
  Millivolt current convector.
  Off gas combustion air flow indicator and transmitter.
Check condition of thermocouple.
Zero, calibrate, and check operation:
  Gas purifier pressure indicator.
  Gas purifier discharge pressure indicator.

Combustion Air Fans

Six fans, three for the kiln and three for the gas purifier, supply air for combustion of the shredded refuse in the kiln, the kiln-off gas in the gas purifier, and the supplemental fuel oil in both the kiln and the gas purifier. To permit the control of the combustion and thermal reactions, the fans are each equipped with inlet dampers and/or manual slide gates whose settings establish the volumetric rate of air intake and the distribution of the discharged air, respectively.

Description

Each of the six fans is a centrifugal type manufactured by Chicago Blower. The three fans for the kiln are a refuse combustion air fan, a turbine-driven kiln combustion air fan, and a motor-driven kiln combustion air fan. The three fans for the gas purifier are a gas purifier combustion air fan, a crossover combustion air fan, and a dust collection fan. Except for the dust collection fan, the air flow rate of each fan is regulated by an inlet damper. Fitted to each damper is an automatic Bailey pneumatic controller whose damper adjustments are governed by the operator in the main control room.

Located on the ground beside the kiln fire hood and driven by a 125-hp motor, the refuse combustion air fan projects the air into a discharge duct equipped with a manual slide gate. When the gate is open, the air flows in a concentrated stream directly into the fire hood; when it is closed, the air flows to an air bustle which directs the air around the circumference of the fire hood for its uniform distribution within the kiln vessel.

To provide air for burning the supplemental fuel oil in the kiln heatup and standby burner, the turbine-driven kiln combustion fan is installed directly below this burner and discharges all air into its windbox. The fan is driven by a Cappus Model RL steam turbine which is powered by steam from either the atomizing steam boiler or the main waste heat boilers discussed later.

To supply air for burning the supplemental fuel oil in the main kiln on-stream burner and some additional combustion air for burning refuse in the kiln, the motor-driven kiln combustion fan is installed directly below this burner. Driven by a 40-hp motor, this fan projects the air into a discharge duct equipped with a manual slide gate. When the gate is open, the air flows to the burner windbox; when it is closed, the air flows to the air bustle in the kiln fire hood.

To provide air for burning the supplemental fuel oil in the start-up burner at the inlet end of the gas purifier, the gas purifier combustion air fan is installed directly below this burner. Driven by a 100-hp motor, this fan discharges all air into the burner windbox.

Designed to provide the gas purifier with the air for burning the kiln-off gas, the crossover combustion air fan is located beneath the crossover duct between the kiln feed hood and the gas purifier. Driven by a 125-hp motor, this fan projects all air into the crossover duct which discharges into the gas purifier.

Intended to provide additional air for burning the kiln-off gas in the gas purifier, the dust collection fan is located below the ram feeder housing behind the kiln feed hood. Driven by a 75-hp motor, this fan projects the air into two discharge ducts each equipped with a manual slide gate. One of these ducts terminates at an atmospheric vent near the fan, and the other branches into two ducts both connecting to the crossover duct.

The five motor-driven fans are interlocked with the induced-draft fan so that they will stop whenever the induced-draft fan has an emergency shutdown. The turbine-driven fan has an overspeed safety device which stops the fan whenever its speed exceeds a preset limit.

Operating Experience

As described above, the air intake and distribution of the fans is regulated by inlet dampers and/or manual slide gates in the discharge ducts. The damper for the refuse combustion air fan is operated in either the manual or the automatic mode. In the manual mode, the operator in the main control room sets the control dial for the damper positioning at a desired percentage of the air flow capacity. In the automatic mode, the damper setting is automatically determined by the product of the mass rate of refuse into the kiln as measured by the belt scale and a variable air-to-refuse ratio set by the operator. Usually operated with a damper setting of less than 50 percent, the fan has an operational range of 90 to 530 m^3 (3,180 to 18,700 ft^3) per minute. The manual slide gate in the discharge duct is usually completely closed so that virtually all the air flows to the air bustle for its uniform distribution within the kiln.

The damper setting for the turbine-driven kiln combustion fan, which supplies air for the kiln heatup and standby burner, is automatically determined by the product of the rate of fuel oil into the burner and a variable air-to-fuel ratio set by the operator. Usually operated with a damper setting of less than 25 percent, the fan has an operational range of 120 to 370 m^3 (4,240 to 13,070 ft^3) per minute.

The damper for the motor-driven kiln combustion fan, which supplies combustion air for both the kiln on-stream burner and the refuse burning, is automatically set similarly as the damper for the turbine-driven kiln combustion fan. This fan has an operational range of 160 to 680 m^3 (5,650 to 24,010 ft^3) per minute. The manual slide gate in the discharge duct is generally nearly closed so that most of the air flows to the air bustle.

The damper for the gas purifier combustion air fan, which supplies air to the start-up burner in the gas purifier, is automatically set in a manner similar to the dampers for the two kiln burner combustion fans. While the maximum capacity of this fan has not been measured, its minimum capacity is 335 m^3 (11,830 ft^3) per minute.

The motor for the crossover combustion air fan, which supplies air for burning the kiln-off gas in the gas purifier, is usually off during operation. When operated in the manual mode, the operator in the main control room sets the control dial for the damper positioning at a desired percentage of the air flow capacity. When operated in the automatic mode, the dampers were automatically modulated to maintain a predetermined gas purifier temperature. The fan has an operational range of 225 to 670 m^3 (7950 to 23,660 ft^3) per minute.

As mentioned above, the dust collection fan is not equipped with an inlet damper. The manual slide gate in the duct to the atmospheric vent is rarely opened, and the similar gate in the discharge duct which branches into two ducts connecting to the crossover duct is always opened. This gate is usually at a fixed position since adjustments have a negligible effect on the airflow.

Since the fan selection was based on the required maximum capacity plus a large safety factor rather than on the operational range, the minimum capacities of the fans have exceeded the normally required operating flow. The capacities of the crossover combustion air fan and the gas purifier combustion air fan were especially high since the kiln-off gases required less air than estimated for total combustion. The high capacity of the former fan produced a back pressure in the crossover duct which in turn produced such a positive pressure in the kiln feed hood that pyrolytic gases were forced through the kiln air seal. Also, the high capacity of the latter fan so projected the flame front into the gas purifier that the temperature at the inlet was lower than those downstream. Consequently, the motor for the crossover combustion air fan is usually off, and the motor for the gas purifier combustion air fan is now used only during heatup and standby operation.

Designed primarily to induce the air flow through the cyclone dust collectors in the size reduction and the storage and recovery modules, the dust collection fan originally discharged into the inlet of the crossover combustion air fan located beneath the crossover duct between the kiln feed hood and the gas purifier. However, when the operation of the crossover combustion air fan was discontinued, two discharge ducts connected directly to the crossover duct replaced the one to the inlet of the crossover combustion air fan. The new ducting had the two-fold purpose of providing two balanced-in jets whose direct discharge into the duct would improve the mixing of the kiln-off gas and the combustion air and of eliminating dust accumulation in the crossover combustion air fan.

In addition, to prevent pressure pulses within the kiln vessel from flowing back through the fans, orifice baffles were installed in the two kiln burner windboxes, and a diverter baffle was installed in the discharge duct of the refuse combustion air fan. However, these baffles caused higher discharge velocities and backpressures on the fan side of the baffles.

As mentioned previously in the section on the kiln, the air bustle was retrofitted in the kiln fire hood to improve the stability of the combustion and thermal reactions within the the kiln. Since the air bustle with its more uniform distribution of the air flow improved the efficiency of the combustion air usage as well as the stability of the combustion processes, it reduced the amount of combustion air needed. In addition, the improved airflow has minimized residue slagging at lower feed rates.

Although the wire mesh filter screen on the end of the atmospheric vent for the dust collection fan clogs rapidly, it is very inefficient since most of the particulate is fine dust. Consequently, a more effective type of filter system is needed.

Pieces of rag and dust accumulating on the dust collection fan rotor caused blower imbalance and frequent cleaning. After glass grit falling from the ram feeder housing had abraded the fan bearings, a protective roof was installed over the entire dust collection fan assembly.

Maintenance

While the dust collection fan must be cleaned regularly to prevent severe vibration, shaft misalignment, and bearing damage, the other fans have required only scheduled preventive maintenance (Tables 22 and 23). The Bailey pneumatic controllers have occasionally required corrective maintenance to remedy malfunctions due to their operation in a dirty environment. However, routine prevention maintenance has generally sufficed for their proper functioning.

Burners and Supplemental Fuel Systems

The burners in the kiln and gas purifier were intended primarily for the two-fold purpose of providing the heat to initiate the thermal processes and then, after the thermal reactions become self-sustaining, of serving as ignition sources. The reactions are self-sustaining when the gasification is sufficient to drive the endothermic processes in the kiln and to maintain the process temperature in the gas purifier (afterburner). This condition usually takes effect about 45 minutes after the ram feeders have started extruding the shredded waste into the kiln.

Description

Except for two propane burners, the 11 kiln and gas purifier burners are part of the No. 2 fuel oil burner system. This system includes a storage tank, two parallel fuel oil pumps, a receiver (accumulator) tank, two kiln main burners, four kiln safety pilot burners, a gas purifier main burner, a gas purifier pilot burner, and a slag taphole burner. In addition to the two propane burners which are also used for the slag taphole, the propane burner system consists of three propane storage tanks and a vaporizer unit.

The fuel oil storage tank, which also supplies the fuel to the steam-atomizing boiler, is above ground at the rear of the plant about 300 m (1000 ft) from all processing vessels. The tank has a working capacity of 453,600 liters (1200,000 gallons) and a total volume of 502,740 liters (132,825 gallons). The tank, constructed of 5-mm (0.25-in.) carbon steel, is equipped with a digital readout level indicator.

Supplying all fuel oil burners, the two fuel oil pumps are Worthington centrifugal units. Installed on a slab near the storage tank, the pumps have parallel piping to permit the operation of one pump while the other serves as a spare. However, the pumps can be operated simultaneously for maximum oil flow. Each pump is powered by a 20-hp motor and has a capacity of 1,890 liters (500 gallons) per minute at a pressure of 1,035 kPa (150 psig) and a fuel oil density of 875 kg m^3 (54.7 lb/ft^3).

Installed in the kiln fire hood, the two kiln main burners are steam-atomized 95,000 MJ/hr (90 M Btu/hr) John Zink units: one is the heatup and standby burner usually set at 69,000 MJ (65 M Btu) per hour and the other is the on-stream lead burner usually set at 13,000 MJ (12.5 M Btu) per hour. Each burner is equipped with a flame scanner, FIA Safety controls, and a

TABLE 22. PREVENTIVE MAINTENANCE SCHEDULE

Kiln Combustion Air Fan, and Turbine

Daily

Check oil level in turbine and governor.

Monthly

Check bearing and turbine for vibration or excessive heat, and reducer oil level.
Lubricate fan bearings and coupling (LiEP2).
Change the oil in both reservoirs on the turbine and check for any moisture (Paradene 430).

Semiannually

Change reducer oil (EP8).
Grease motor (LiEP2).

Annually

Zero, calibrate, and check operation:
  Fan discharge pressure indicator.
  Steam to kiln combustion air fan turbine pressure indicator.
Clean, lubricate, and calibrate:
  Air supply pressure to inlet vane drive.
  Kiln combustion air fan low discharge pressure alarm.
  Kiln combustion air fan low discharge pressure switch.

TABLE 23. PREVENTIVE MAINTENANCE SCHEDULE

Refuse, Kiln, Crossover, Gas Purifier Combustion Air and Dust Collection Fans

Monthly

Visually check V-belts for tension and wear.
Check bearings and motors for vibration or excessive heat.
Lightly grease refuse air fan bearings (LiEP2).

Quarterly

Grease wheel shaft in kiln, gas purifier, crossover combustion air, and dust collecting fans.

Semiannually

Check motor, bearing condition, alarms, and interlocks.

Annually

Check V-belts for tension and wear.
Check bearings and motor for vibration.
Clean balance rotor if necessary.
Megger and lubricate motor (LiEP2).
Zero and calibrate:
    Temperature ratio station.
    Current to pneumatic convector.
Clean, lubricate, and check air supply pressure to inlet valve drive unit.
Zero, calibrate, and check operation of pressure indicator.

high-energy ignitor. The ignition of each burner is controlled locally by a free-standing control panel and remotely by the control room.

Located in the kiln feed hood, the four kiln safety pilot burners are steam-atomized Peabody units each incorporating a combustion air fan and having a fixed firing rate of 74 MJ (70,000 Btu) per hr. While the ignition of each burner is controlled remotely by the control room, the combustion air for each is regulated by a control on the burner assembly.

The main, or start-up burner for the gas purifier is a steam-atomized John Zink unit with a capacity of 169,000 MJ (160 M Btu) per hr. The start-up burner is in the center of the inlet of the gas purifier. Immediately above the start-up burner is the pilot burner for the gas purifier. Also a steam-atomized John Zink burner, the pilot burner has a fixed firing rate of 1,055 MJ (1 M Btu) per hr and an induced draft since, unlike the start-up burner, it does not have a fan source supplying combustion air. Like the two kiln main burners, the two gas purifier burners are each equipped with a flame scanner, FIA safety controls, and a high-energy ignitor. Also the ignition of each of the two gas purifier burners is controlled locally by a free-standing control panel and remotely by the control room.

The fuel oil burner installed in the slag taphole is a Peabody R10 steam-atomized unit with a fixed firing rate of 3,200 MJ (3 M Btu) per hr. Equipped as the two kiln main burners, this burner also has a horn to sound a flame failure and a built-in combustion air fan with local start/stop control. The ignition is controlled locally by a free-standing control panel.

Located about 50 m (165 ft) from all processing vessels, the three propane storage tanks each have a capacity for 1,890 liters (500 gallons). Operated nearby and in conjunction with the slag taphole fuel oil burner, the two propane burners (Figure 60) are John Zink units. Equipped with a flame scanner and a solenoid-operated shutoff valve, each of the propane burners has a capacity of 3,165 MJ (36 M Btu) per hr.

Operating Experience

Except for the fuel oil storage tank overflowing through the fill line and an incident when vandals closed the manual valves in the fuel oil pump lines while the pumps were operating, there were no disruptions in the tank and pump operations. The tank overflowing was remedied by installing a check valve in the fill line.

The firing rate of the kiln heatup and standby burner is manually set at a desired percentage of its capacity. Since this burner has the primary purpose of maintaining the kiln temperature when refuse is not being processed it is usually turned off when the kiln reactions become self-sustaining. The burner nozzle was modified several times before the current tip was installed to produce a long 12-m (40 ft) cylindrical flame pattern.

Figure 60. Propane burners in the slag taphole.

Like the kiln heatup burner, the firing rate of the kiln on-stream lead burner is manually set at a desired percentage of its capacity. While this burner was intended to ignite any combustible gases accumulating in the kiln fire hood and to provide supplemental heat for sustaining the thermal processing in the kiln vessel, its need is questionable since the kiln thermal reactions have been self-sustaining and the combustible gas accumulations are unlikely because of the high temperature and turbulence in the fire hood. Moreover, the kiln has operated satisfactorily without the firing of either of the two main burners. The nozzle for this burner was also modified several times before the current tip was installed to produce a short spherical flame pattern.

The four kiln safety pilot burners were intended to ignite any combustible gas/air mixtures that might develop in the kiln feed hood because of air leaking through the ram feeder and hood seals. However, like the kiln on-stream lead burner in its function as an ignition source, the need for the safety burners is also questionable since the development of the explosive gas pockets is unlikely with the prevailing high temperature and turbulence in the feed hood.

Nevertheless, the additional safety factor that these burners provide may outweigh their cost. The original induced-draft, John Zink safety burners were replaced with the current Peabody burners, each incorporating a combustion air fan. The original John Zinc burners relied on induced-draft openings for combustion air. However, when positive pressure pulses occurred within the kiln, the hot pyrolytic kiln gas blew back through the burners extinguishing the flames and thermally damaging the burners. These burners were replaced with the Peabody safety burners described earlier because the combustion air fan incorporated into each burner prevented any blowback through the burners during positive pressure pulses within the kiln.

As designed, the gas purifier start-up burner has provided the heat to establish and maintain the process temperature of the gas purifier exit gases whenever there is an interruption of the refuse processing within the kiln. As the thermocouple at the rear of the gas purifier senses the process temperature and transmits a corresponding signal to the control room, the control system automatically adjusts the burner firing rate whenever the process temperature varies from the temperature set by the operator.

The need for the gas purifier pilot burner, whose prime purpose is to serve as an ignition source, is questionable since the process temperature established by the gas purifier start-up burner, 1300°C (2350°F), is sufficient to ignite the kiln-off gas. In fact, the gas purifier has frequently processed the kiln-off gas satisfactorily without the firing of this burner. Moreover, any of the three burners in the slag taphole could serve as the ignition source.

Intended to minimize the solidifying of the molten slag in the slag taphole, the Peabody fuel oil burner installed in the hole is operated continuously during standby and deslagging periods as well as during the kiln-off gas processing.

Operated intermittently whenever solidified slag begins to accumulate, the two propane burners in the slag taphole have a fixed firing rate. The air inlet to each burner is regulated so that the minimum amount of air may enter the hole and cool the slag whenever the burner is off.

The burner ignition system has proved extremely unreliable because of the apparent underdesign of the ignition transformer, the exposure of circuits and contacts to weather, the deterioration of the ignition wire insulation, and the operational complexity of the ignition cycle.

Since many fuel oil burner malfunctions have been due to the steam fouling of the burner filters and strainers, several operators have stated that air atomizing would be preferable to the current steam atomizing. In further support of this contention, no additional equipment would be needed since an air compressor is available, the steam-atomizing boiler had had numerous malfunctions, and the pneumatic lines would be much easier to maintain. In addition, the high radiant heat environment of the burners has caused many burner malfunctions and electrical wiring failures. After a burner failure, the purge of the burner system delays the restart of the burners and, consequently, allows the processing temperature to drop. The lack of automatic temperature controls in all burners also increases the burner operational requirements.

Originally, the two kiln main burners and the gas purifier start-up burner were each interlocked with their respective combustion air fans as follows: If the discharge pressure switch in the burner windbox failed to detect the pressure due to the fan airflow, the burner would be shut off. However, when the baffles were installed in the two kiln main burners, as discussed above the airflow was so changed that the pressure sensor could no longer properly detect its presence. Consequently, all burner interlocks were disconnected.

Maintenance

The fuel oil burners sustained many steam and oil leaks which required extensive corrective maintenance. Of the four kiln safety pilot burners in the feed hood, the one in the emergency stack of the hood has required frequent repair because its wire insulation was usually melted or burned when the stack lid opened. The preventive maintenance schedules for the fuel oil burner system and the fuel oil pump are shown in Tables 24 and 25, respectively.

Residue Quency Tank and Conveyor

After the shredded refuse has been processed in the kiln, the residue (ash, other inert solids, and some uncombusted carbon char) tumbles into the kiln fire hood where it falls vertically into a water bath contained by the residue quench tank. As the residue settles to the bottom of the tank, a drag chain conveyor transports it along the tank bottom and then up a continuous incline which serves first as the forward end of the tank and then as a dewatering deck. As the residue ascends the dewatering deck, it either continues to the top of the incline where it is discharged onto the vibrating residue screen conveyor in the residue separation building or falls en route through a flop gate whenever the gate is opened into a truck.

Since the residue quench tank completely encloses the bottom of the fire hood while still allowing the residue discharge, it serves as an air seal to maintain a negative pressure within kiln fire hood and vessel as well as a means for cooling the hot residue and then removing it.

Description

As shown in Figure 61, the residue quench tank is a carbon steel construction with a rectangular base, vertical side walls, and outwardly oblique end walls. Sloping at a 25° angle from the horizontal, the forward end wall is part of a continuous, constant-width incline which serves as a dewatering deck above the water level. The upper surface of the tank bottom

TABLE 24. FUEL OIL BURNER SYSTEM PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Inspect all safety burners, tips, and fire-eye for cleanliness.
Check fire-eye and pilot ignition for cleanliness.
Check operation of oil pump, pump motor, and oil pressure controller.
Check operation of alarm contactors, boiler feedwater level switch, level and shutdown alarms.
Check condition of programming controller.
Check for proper voltage on secondary ignition transformer.
Check general condition of pressure impulse line.
Check proper operation of pressure controllers (on/off and hi/low fire).
Grease motor bearings (LiEP2).

Quarterly

Replace filter in kiln safety burner and slag hole Peabody burner.

Semiannually

Pull burner tips on kiln heatup and standby burner, kiln on-stream burner, gas purifier heatup and standby burner and inspect for erosion or damage.
Inspect all filters and change if necessary.
Clean strainers in kiln heatup and standby burner, kiln on-stream burner, gas purifier heatup and standby burner.
Check all burner blower motors.
Check alarm.
Check operation and cleanliness of kiln heatup and standby burner, kiln on-stream burner, gas purifier heatup and standby burner and burner blower pressure switches.
Check ignition conditions of kiln heatup and standby burner, kiln on-stream burner, gas purifier on-stream burner, gas purifier heatup and standby burner.
Check condition of all burner pressure gauges and solenoid valves.

Annually

Check all burner electrical controls, timers, and relays.
Megger motors.

TABLE 25. FUEL OIL PUMPS PREVENTIVE MAINTENANCE SCHEDULE

Weekly

Check bearings, oil level, seals.

Monthly

Tighten nuts--teflon sticks on three valves at pumps and two at oil tank.

Quarterly

Lubricate bearings with pyroplex (EP2).
Grease valves at pump and tank (LiEP2).

Semiannually

Grease motor (LiEP2).

Annually

Zero, calibrate, and check operation:
    Fuel oil pump discharge pressure indicators.
    Fuel oil system pressure indicator.
Clean and lubricate:
    Fuel oil totalizing indicator.
    V8 fuel oil storage tank level indicator.

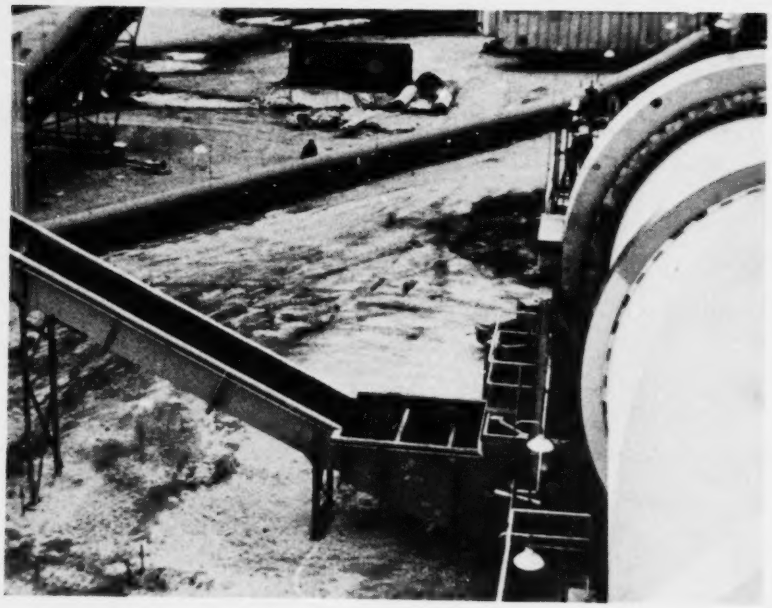


Figure 61. Original residue quench tank and conveyor.

and the entire incline is lined with abrasion-resistant steel plate. The tank is 2.3 m (7.5 ft) high and was designed to contain 42 m^3 (1500 ft^3) of water with a 30-cm (12-in.) freeboard. The makeup water filling the tank consists mostly of clarifier underflow, discussed later, and some city water.

As mentioned above, a flop gate in the bottom of the dewatering deck allows the residue to fall into trucks for landfill disposal before it reaches the top of the incline for discharge onto the vibrating residue screen conveyor in the residue separation building. Pneumatically operated, the gate is as wide as the deck and 60 cm (24 in.) long.

On the residue discharge run, the drag chain conveyor extends along 11 m (36 ft) of the horizontal part of the tank and then along the 21 m (69 ft) of the entire 25° incline. The conveyor consists of two parallel chains of welded steel links connected at 60-cm (2-ft) intervals by vertically positioned drag flights constructed of 6-mm (0.25-in.) thick abrasion-resistant steel channel. Driven by a 40-hp motor, the conveyor runs at 9 m (30 ft) per minute. The drag chain conveyor was designed to transport 45 m^3 (1600 ft^3) of residue per hour.

The drag chain conveyor is interlocked to the vibrating screen conveyor so that it cannot run unless the screen conveyor is operating.

Operating Experience

While the conveyor width extends close to the original tank side walls, residue falling between the walls and the conveyor required installing artificial walls which slope downward from the original walls to extend just above and inside the conveyor. In addition, a catwalk and better lighting were installed around the tank for safer and more efficient working conditions.

Originally the only provision for draining the tnak was a small 76-mm (3-in.) I.D. pipe which rapidly plugged with solids during the initial operation. Consequently, a door was installed on the side of the tank to gain access to the tank area for cleaning as well as to drain the tank. However, this removal of the water with its considerable waste content contaminates the environment, as discussed later in the environmental assessment of the plant, because the water flows directly into a nearby drainage channel without any treatment.

During the plant shakedown, grizzly bars were placed across the top of the tank to prevent large slag balls from jamming the conveyor. However, when the residue accumulating over the bars became so excessive that the entire plant processing had to be shut down to remove the debris, the bars were removed.

When the tank water level was increased to provide a better air seal, the freeboard was so reduced that the tank has been constantly overflowing. This condition has been aggravated by the water level controllers, called bubblers, frequently malfunctioning because of their rapidly becoming plugged with floating solids.

Whenever there are sufficient accumulations of the carbon char part of the residue floating on the water, the char continues to burn until it fuses into slag and sinks. This burning and slagging, however, is less severe than it was when magnetic materials were removed from the shredded refuse stream. The greater density of these materials accelerated the sinking process.

To rapidly vent the kiln vessel whenever there is an emergency shutdown of the induced-draft fan, interlocks open both the lid of the emergency stack in the kiln feed hood and an emergency drain in the residue quench tank. Then as the water drains to break the air seal in the fire hood, a draft is established for airflow into the fire hood and out of the feed hood. Controlled by a pneumatically operated valve, the emergency drain has never functioned properly because of its tendency to jam and valve and because of valve malfunctions. Nevertheless, the kiln vessel has always been satisfactorily vented in the emergency situation since the turbine-driven combustion air fan has provided a sufficient air flow through the vessel and out of the feed hood.

While the drag chain conveyor has a design capacity of 45 m^3 (1600 ft^3) of residue per hour, the actual volumetric flow rate varies considerably with the residue quality. When the quality is poor with large quantities of unprocessed refuse, the drag flights are usually completely full. When the quality is good, the drag flights are only about one-third full. When the residue quality is poor and slag balls are formed from overprocessed refuse, the slag balls occur approximately every third flight. Despite the marked differences between the design residue bulk density of 800 kg per m^3 (50 lb/ft^3) with a moisture content of 50 percent and the average measured bulk density of about 1600 kg per m^3 (100 lb/ft^3) with a moisture content of 31 percent, the major deficiency in the conveyor design was due to the underestimation of the maximum particle size. Whereas the design maximum was 10 cm (4 in.) with an occasional 60-cm (24-in.) long pipe, slag balls have been as large as 2 m (6 ft) in diameter.

In the original conveyor configuration when the return run was within the residue quench tank (Figure 61), the slag balls caused two types of conveyor failure. In one type, because of their excessive loading, the slag balls would break the shear pin and damage the drag flights. In the other type, slag balls falling on the conveyor return run would either pass partially through the return run to become wedged between the drag flights of the return and discharge runs or be carried over to the rear of the tank to become wedged between the conveyor and the section of the tank end wall near the tail sprocket. On one occasion, the entire tail sprocket was pulled out due to slag ball jamming. Therefore, the conveyor was completely redesigned to provide greater structural strength and motor power, and the return run was changed to travel over the kiln fire hood and then down to the tail sprocket (see Figure 62) After these modifications, the flights have withstood the loads better with considerably less damage and the shear pin rarely breaks.

After the return run was placed over the fire hood, excessive residue accumulated on the return deck since residue retained on the drag flights as the flights started the return run would dry and flake off, especially when agitated by the wind or the conveyor vibration. Therefore, to minimize the residue retention as well as the wedging of cans between the chain and the head sprocket, relief notches were cut into the drag flights.

As the links in the conveyor chain stretch, and the chain consequently becomes loose, the conveyor has an oscillating motion during the return run. The motion consists of jerky starts and stops with the conveyor vibrating between the conveyor idlers. To overcome the chain looseness, the diameter of the idlers was increased, and the chain has teen tensioned by removing a link or adjusting the return guide rail.

To provide a detector of slag balls forming in the kiln and ascending on the drag conveyor, a horizontal shaft with vertical bars welded to it was installed across the sides of the dewatering deck. With the rods extending to the upper extremity of the drag flights, the shaft rotated a constant angular sweep when only a flight contacted the rods. Since a switch contact was activated with each such rotation, the shaft assembly also served as a

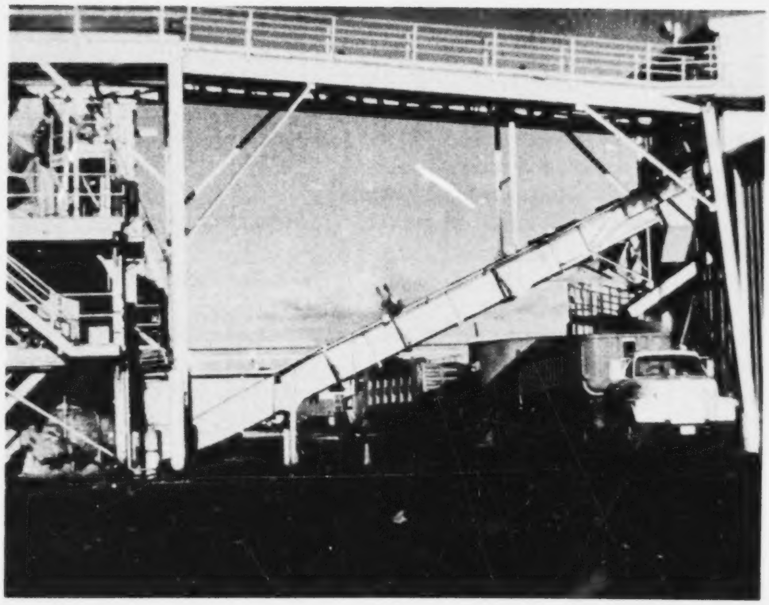


Figure 62. Modified residue quench tank and conveyor.

zero speed sensor, that is, as a means of monitoring the conveyor running. When a slag ball extending above the flights contacted the rods, the shaft rotated further than the normal sweep and accordingly tripped a switch which activated an alarm. However, after large slag balls had severely damaged this slag detector because of the limited clearance between the horizontal shaft and the drag conveyor, the shaft assembly was replaced with a photoelectric detector. The latter detector has functioned adequately except for instances when steam from the residue blocks the light path. While this light path interference prompted consideration of a sonic detector, such a detector has not as yet been purchased.

To prevent slag balls from interfering with the head sprocket drive system, the sides of the dewatering deck above the residue flop gate bypass were removed to allow slag balls to fall off the deck before reaching the head sprocket. However, slag balls larger than 1 m (3 ft) in diameter must be removed by a small mobile crane.

Maintenance

Table 26 is the preventive maintenance schedule for the residue quench tank.

The drag conveyor has required considerable emergency maintenance in addition to the normal routine maintenance (Table 27). Before the conveyor was redesigned, there were frequent pin shearings, flight damages, chain link breaks, and chain jumps off the lead sprocket. In addition, the motor

TABLE 26. QUENCH TANK PREVENTIVE MAINTENANCE SCHEDULE

Semiannually

Check operation of solenoid valve.
Check air supply pressure.
Check condition of pneumatic cylinder.
Zero and calibrate current pneumatic converter.

Annually

Check operation of solenoid valve, air supply pressure, operation of pneumatic cylinder, and electrical system.
Check operation of level switches, low level alarm, and pressure switches.

TABLE 27. QUENCH TANK CONVEYOR PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check drag for loose bolts, damaged flights or support brackets, unusual wear, and unusual noise.
Check tension on drag chain, adjust as required.
Check reducer for abnormal heat, noise, and oil level (Paradene 475).
Check alignment of head shaft.
Top up lubricant in drive chain (Paradene 430).
Grease headshaft and idler shaft bearings (LiEP2).

Shutdown

Drain and clean tanks.
Inspect tanks and wear plates for wear or damage.
Check drag guides for damage.
Check tailshaft bearings and sprocket.

Semiannually

Change reducer oil (Paradene 475).
Lubricate coupling and motor (LiEP2).
Check motor, alarm and interlocks, zero speed switch and bearings.
Lubricate bearings (20 W motor oil).

Annually

Megger motor.

had to be realigned and its drive and coupling repaired, and the guide rails had to straightened. After the conveyor modifications, however, very few pins have sheared and the chain links have remained intact although the flights are still damaged and the chain continued to jump the head sprocket but much less frequently than before the modification.

After the above mentioned provisions and procedures were introduced to minimize the chain loosening, the adjustments to maintain the required chain tension have been minor, and a straightening of the chain guide is not likely to be needed again.

Seal Tank and Screw Conveyors

The air seal for both the kiln feed hood and the gas purifier is maintained by a single water quench tank into which the bottom of the feed hood is submerged at one end and the bottom of the slag taphole of the gas purifier is submerged at the other end. In the tank below each of the two submerged bottoms is a screw conveyor, one for the spillback and dust discharged from the feed hood and the other for the molten slag discharge from the slag taphole. As the respective discharges fall into the water to be cooled and shattered into frit while settling, the conveyors transport the frit toward the middle of the tank where a third screw conveyor, called the frit transfer conveyor, elevates and dewaters the frit before discharging it into a dump truck for landfill disposal.

Description

The water-filled seal tank common to the kiln feed hood and the gas purifier is a horizontal carbon steel construction in an inverted triangle configuration with a rounded bottom to accommodate the spillback and slag conveyors. With a design freeboard of 15 cm (6 in.), the tank is 16 m (52 ft) long and 1.1 m (3.5 ft) deep. Figure 63 shows the bottoms of the kiln feed hood and the slag tap hole of the gas purifier submerged in the seal tank. The tank is equipped with a water recirculating system which includes a surge tank, a level controller, a recirculation pump, and two nozzles that protrude through the slag hole periphery and below the water level in the slag discharge area.

Extending from outside the tank at the kiln end to the transfer conveyor, the water-submerged, 10-m (33-ft) long spillback conveyor runs along the tank bottom and is supported at its inlet end by a pillow block bearing and at its discharge end by a hanger bearing. The water seal at the junction of the conveyor shaft and tank end is maintained by a teflon-coated, fiber-packed gland. The conveyor is powered by a 7.5-hp motor which is installed at the exterior end of the conveyor shaft.

Like the spillback conveyor, the slag conveyor extends from outside the tank at the gas purifier end to the transfer conveyor. With the same type of placement, bearings, and water seal as the spillback conveyor, the slag conveyor is 5.8 m (19 ft) long and is driven by a 10-hp motor also installed at the exterior end of the conveyor shaft.

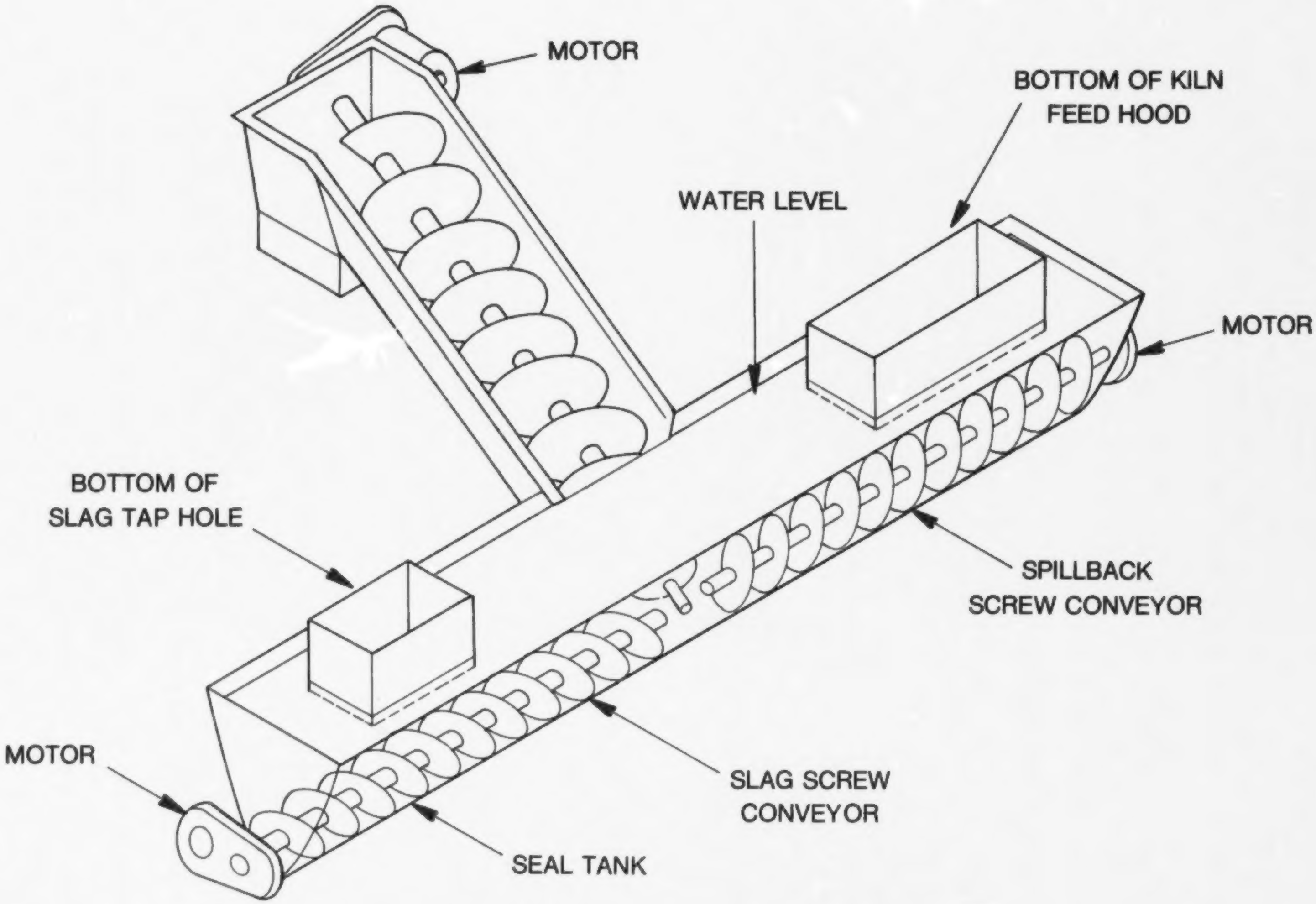

MOTOR
BOTTOM OF KILN FEED HOOD
WATER LEVEL
MOTOR
BOTTOM OF SLAG TAP HOLE
SPILLBACK SCREW CONVEYOR
MOTOR
SLAG SCREW CONVEYOR
SEAL TANK

Figure 63. Schematic of the seal tank.

From the discharge area of the spillback and slag conveyors, the 7.8-m (25.5-ft) long transfer conveyor is inclined at a 30° angle to rise out of the water for frit dewatering before discharging the frit into a truck. The transfer conveyor is powered by a 7.5-hp motor installed at its discharge end and is supported at its inlet end by a thrust bearing and at its discharge end by a pillow block bearing. The spiral flights above the water line are notched to accelerate the frit dewatering.

The slag and spillback conveyors are interlocked with the transfer conveyor so that they will shut down if the transfer conveyor stops to prevent the buildup of frit at the inlet end of the transfer conveyor.

Operating Experience

As with the residue quench tank in the kiln fire hood, the seal tank, common to the kiln feed hood and gas purifier, has been constantly overflowing after the water level was raised to provide a better air seal. In addition, the very small tank drain, 76 mm (0.3 in.), the only opening in the original tank, rapidly plugged with solids. The water level controller malfunctions caused low water level whenever its bubbler was plugged with solids. When the bubbler was so clogged, the pressure in the controller air line remained high irrespective of the water level which in turn caused the inlet water valves to remain closed. Since the tank had to be cleaned as well as drained when the tank drain was plugged, a door was installed in the tank for this two-fold requirement. However, the door is difficult to open without getting wet, and the water with its environmentally objectionable content is discharged directly onto the ground without any treatment.

During the shakedown period, the tank rotated slightly whenever a screw conveyor torqued because of slag balls jamming between the conveyor and a tank side. Consequently, the tank was sufficiently reinforced with structural steel to resist the torquing.

The abrasiveness of the frit coupled with the screw conveyor forcing the grit along the tank surface has caused such severe wear that leaks have developed in the tank bottom.

Since the tank water within the submerged part of the slag taphole becomes stagnant and is much hotter than the rest of the tank water, a water recirculating system was installed. As intended, the cooler water in the slag taphole would have two desirable effects: First, since a lesser amount of the relatively cool steam would rise into the gas purifier, not as much of the molten slag would solidify, and consequently the plugging of the slag tap-hole would be reduced. Second, the molten slag falling into the cooler water would be shattered more thoroughly into frit or formed into smaller balls since large masses of molten slag cannot be cooled fast enough for complete fritting. As a minimum benefit, the limiting of the slag ball size would be very desirable since the large slag balls have been the most damaging factor in the conveyor operation.

When the water recirculating system was installed, process water would overflow a weir in the seal tank and flow by gravity in a trough to the surge tank where the recirculating pump would force the water through the two nozzles in the slag taphole periphery and into the water within the submerged part of the hole. Since the surge tank was not equipped with sludge removal equipment, it had to be cleaned frequently because of excessive accumulations of solids settling within the tank. Consequently, the inlet pipe for the recirculating pump was moved to the seal tank itself and a screen was placed before the pump inlet to prevent solids from damaging the pump and plugging the nozzles. However, after the pump was damaged by grit that flowed through the screen and the nozzles continued to plug, the operation of the water recirculating system was suspended. Stopping of the recirculating system did not seem to increase the plugging of the slag taphole or decrease the fritting of the molten slag.

Originally, there was only one bottom conveyor which extended along the entire length of the seal tank and was driven by a single motor installed on the conveyor shaft outside the tank at the kiln end. When the conveyor began to flex excessively, it was converted into two separate bottom conveyors by cutting it at the inlet end of the transfer conveyor and then installing a hanger bearing on each side of the cut and a second motor and drive system on the conveyor shaft outside the tank at the slag taphole end. Since the hanger bearings were initially close to the conveyor feed stream, they blocked the flow of large slag balls and, therefore, were moved to the conveyor ends. As the hanger bearings are submerged and water-lubricated, they sustain abrasion from the grit in the seal tank water.

After the original single bottom conveyor was separated into the spillback and slag conveyors and the flights were installed in the kiln vessel to move the shredded refuse more effectively down the kiln (as discussed above), the spillback into the kiln feed hood was so reduced that the spillback conveyor has had a minimum loading except for the occasional falling of kiln refractory or wire mesh from the kiln emergency stack lid into the tank.

In contrast to the spillback conveyor, the slag conveyor has had excessive loads that have frequently broken its shear pin. While the strength of the shear pin has been progressively increased to keep the conveyor operational, the greater capacity to handle the excessive loads has caused the conveyor spiral flights to bend. When the conveyor continued to be overloaded, the drive mechanism was upgraded and the original 5-hp motor was replaced with the current 7.5-hp motor. Then while fewer pins were sheared, both the slag conveyor and the transfer conveyor screws became so badly damaged that they were replaced with new screws that have a stronger shaft and spiral edges double the thickness of the original ones. In addition, the pitch was decreased from 45° to about 10°.

To monitor the turning of the slag conveyor screw, a zero speed switch was installed on the drive shaft of that conveyor. However, if the pin linking the drive shaft and the screw fails, the switch will erroneously continue to indicate that the screw is still turning.

The design capacity of the slag and transfer conveyors was based upon a frit bulk density of 800 kg per cu m (50 lb/ft^3) while the average measured bulk density has been 1600 kg per cu m (100 lb/ft^3). The conveyor performance has been adversely affected more, however, by the discrepancies between the maximum design particle size of 8 cm (3 in.) and the actual particle sizes. Slag balls as large as 30 cm (12 in.) have fallen into the seal tank and onto the slag conveyor. Most of the conveyor failures have been due to slag balls wedging between the conveyor flights and the tank sides.

The numerous screw conveyor failures have caused the shutdown of the entire plant to prevent slag frit accumulations in the seal tank that would eventually plug the slag tap hole.

Originally, the trough for the transfer conveyor was misaligned so that the continuous rubbing of the conveyor against the trough damaged the conveyor hanger bearing and abraded holes into the trough until the trough was aligned and structurally reinforced. In addition, the original hanger bearing at the bottom of the conveyor was replaced by a thrust bearing with a water flush. Notches were cut into the conveyor spiral flights above the water line to facilitate the frit dewatering.

Since the transfer conveyor has to carry frit with bulk densities about twice the design bulk density up its 30° incline, it has occasionally evidenced overloading that may require a larger motor.

The access to all three conveyors and the seal tank is difficult because of their elevations and the lack of platforms. Although the drive system at the discharge end of the transfer conveyor is on a platform, the platform is isolated and 6 m (20 ft) above the ground level.

The electric switch boxes for each of three screw conveyors are in the residue separation building. Since this location is too remote for ready access, the boxes should be transferred to the motor control center adjacent to the control room.

Maintenance

All three screw conveyors have required frequent tightening replacement of the packing. After the various modifications to the conveyors because of the many shear pin failures and replacements during the shakedown period, the pins still require replacement but much less frequently. Since its installation on the slag conveyor, the zero speed switch has required considerable repair and was replaced once. Both the pillow block and the hanger bearing for the slag conveyor have required replacement. On one occasion when the water flush was turned off, the thrust bearing for the transfer conveyor had to be replaced. On another occasion, the drive system for the slag conveyor required the repair of the drive sprocket safety lever and the installation of a new hub and bushings on the drive sprockets. The preventive maintenance schedules for the seal tank and the screw conveyors are shown in Tables 28 and 29.

TABLE 28. SEAL TANK PREVENTIVE MAINTENANCE SCHEDULE

Annually

Check operation of level valve.
Check operation of solenoid valve.
Check operation of low level alarm.
Check operation of level switches.

TABLE 29. SCREW CONVEYOR PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check oil level in all three gear boxes.
(Winter - Paradene 475)
(Summer - Paradene X 1000)
Check oil level in chain guards.
Grease thrust bearing on the frit transfer conveyor (LiEP2).

Quarterly

Lubricate couplings and pillow block bearing (LiEP2).
Check packing on spillback and slag conveyors, repack if necessary.

Semiannually

Check moving parts for wear.
Check flight thickness at outside edge, and for bent flights.
Check discharge spouts for excessive wear.
Change oil in the reducer.
(Winter - Paradent 475)
(Summer - Paradene X 1000)
Change drive chain oil (Paradene 430).
Grease motors (LiEP2).
Check motor, flexible cord, and zero speed station for proper operation.
Lubricate local start/stop/job stations.

Annually

Megger motor.
Grease motor bearings (LiEP2).
Waterproof (WD-40 or CR226).

Quench Air Dampers

As the combusted kiln-off gases pass through the horizontal elbow of the gas purifier exit duct to be directed to the waste heat boilers, they are cooled by dilution with ambient air which enters the duct through two openings on opposite sides of the elbow. Since the exit gases contain entrained molten slag, the cooling was designed to quench and solidify the slag before the gases reach the boilers. The air is drawn through the openings because of the negative pressure established within the duct by the induced-draft fan. Each quench air opening is equipped with a manually operated damper to control the air flow.

Description

Each of the two quench air openings is approximately 75 cm (30 in.) in diameter and is lined with castable refractory. One opening is on the inside of the elbow and above the horizontal axis of the gas purifier exit duct, and the other opening is on the outside of the elbow and below the horizontal axis. The upper opening is equipped with a John Zink MA30 slotted stator and air register (Figure 53), and the lower opening is fitted with a butterfly valve damper (Figure 64).

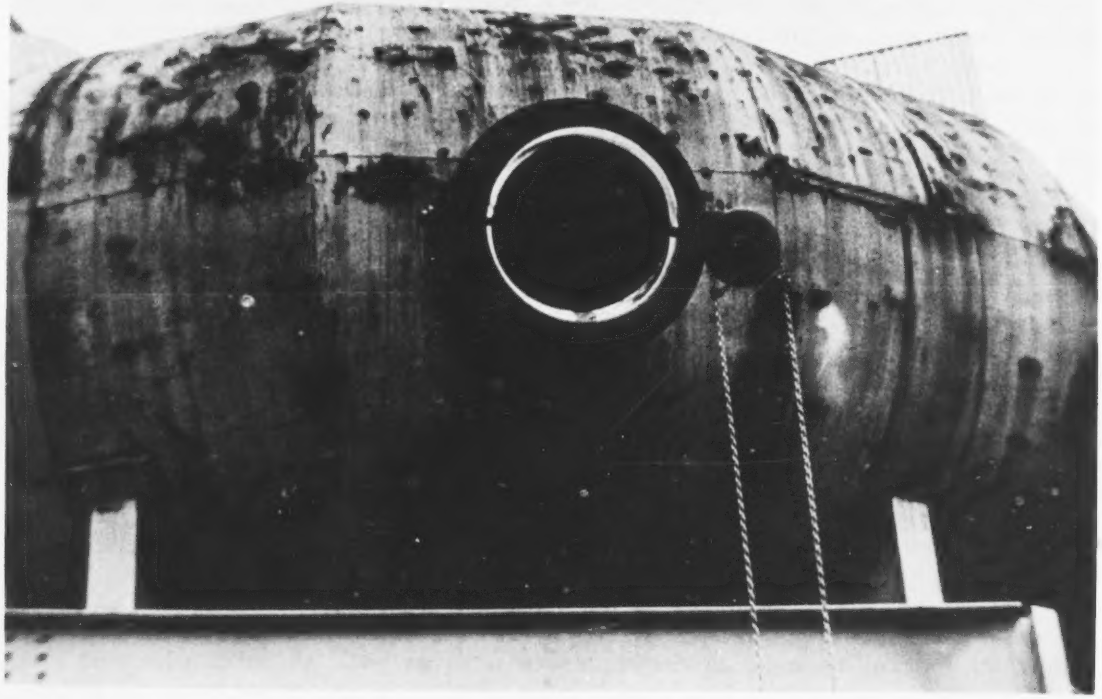


Figure 64. Butterfly valve quench air damper.

Constructed of carbon steel plate, the stator of the slotted air damper is a cylinder open on one end and closed on the other. With the closed end extending vertically outward, the open end is welded to the duct surface around the opening. Evenly spaced around the stator circumference are eight large slots 20 by 36 cm (8 by 14 in.) and one small slot 6 by 36 cm (2.5 by 14 in.). Since the total stator slot area (0.60 m^2, 6.5 ft^2) is larger than the opening area (0.46 m^2, 5 ft^2), the slotted air damper ceases to control the air flow when the exposure of its slots approaches the maximum extent. Like the stator, the air register is a carbon steel cylinder with slots matching those in the stator. The air register is equipped with a manual rigid handle to vary the stator slot openings and, accordingly, the air flow.

Constructed of 315 stainless steel, the butterfly valve damper has a 70 cm (28 in.) diameter. When the damper is completely opened and closed, the inlet air area is 0.46 and 0.06 m^2 (5 and 0.6 ft^2) respectively. The damper setting is positioned by a manual chain pulley which extends to the ground. To provide access into the gas purifier exit duct and for damper maintenance, this damper is hinged.

Operating Experience

Early in the demonstration, the gas purifier exit gases had temperatures of about 1100°C (2000°F) upon entering the inlet to the waste heat boilers. Since this temperature would maintain the gas-entrained slag in the fluid state, molten slag impinged, solidified, and accumulated on the boiler tubes. Consequently, the exit duct of the gas purifier was retrofitted with the quench air openings and dampers that reduced the inlet temperatures to about 870°C (1600°F). As a result, the gases were cooled sufficiently to solidify the slag before the gases entered the waste heat boiler area. Moreover, the air entering the openings is usually sufficient to complete the combustion of the gases exiting the gas purifier with an excess air level of approximately 67 percent.

Although the register for the slotted air damper had jammed in the open position because of heat expansion, this jamming has not posed an operational problen. As subsequently learned, the slotted air damper must remain completely open while the setting of the butterfly valve damper is varied to produce the optimum quench air flow. The rate of the quench air flow is detailed later in the mass and energy balance section.

Maintenance

The only maintenance required of the opening and dampers has been the routine lubrication of the dampers.

Gas Scrubber

A gas scrubber was chosen as the system to treat the flue gases for air pollution control because it could remove acid as well as particulate at a lower capital, operation, and maintenance cost than any other type of treatment system. The scrubber treats the hot flue gases which either have passed through the waste heat boilers and economizers or have bypassed these units by flowing through a jug valve after leaving the gas purifier.

Description

The gas scrubber is a reinforced concrete, vertical, 10-m (33-ft) diameter, cylindrical spray tower 21 m (69 ft) high (Figure 65). The bottom 2 m (6 ft) of the scrubber is filled with water to provide a working water volume of 132,000 liters (35,000 gallons). The gas inlet, which is a 2.4 m (8 ft) wide and 4.8 m (16 ft) high rectangular duct, enters the scrubber tangent to the vertical with the lower extremity of the duct 3 m (10 ft) above the bottom of the scrubber. The gas exit duct, which is centered in the top of the scrubber, is 2.4 m (8 ft) in diameter.

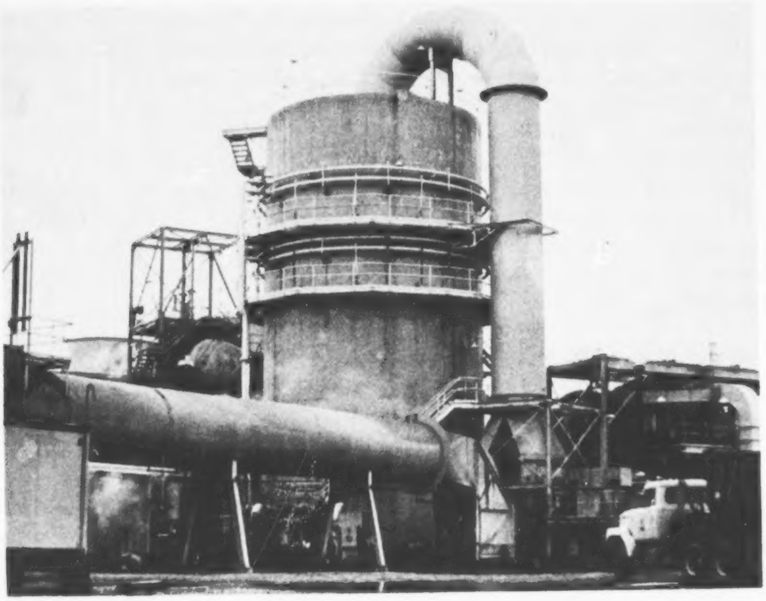


Figure 65. Gas scrubber.

To protect the steel ductwork from thermal damage, the horizontal section of the inlet duct is lined with 23-cm (9-in.) anchored brick, and the sloping transition duct is lined on the floor with 23-cm (9-in.) brick and on the roof and sides with 11-cm (4-in.) of gunite.

As the flue gases to be treated pass through the inlet duct, they are quenched by the water spray within the duct. Upon entering the scrubber near the bottom, the gases flow cyclonically upward to the gas exit duct at the top of the scrubber. Immediately after the inert to the exit duct, the ductwork turn 180° to extend vertically downward to the induced draft fan which draws the gases through the entire thermal processing and energy recovery areas.

As the gases rise to the exit duct, they are cooled and scrubbed of their entrained particulate and vapors by falling fine water droplets which are sprayed by the water recirculating system at the top of the scrubber. The water collecting at the bottom of the scrubber serves as a wet well for the water recirculating system.

To prevent corrosion within the recirculating system, a pH control system maintains a neutral pH in the recirculation water by adding a caustic material to the water. In addition, a solids separation system removed the suspended solids from the recirculation water. The water recirculating, pH control, and solid separation systems will be detailed later. Figure 66 is a schematic of the entire gas scrubber system.

Operating Experience

Since the scrubber had not removed enough particulate to comply with the Federal and State of Maryland particulate emission standards, the following innovations were tested to increase the particulate removal: the constant use of the inlet duct quench sprays, both a low and a high recirculating flow, a low recirculating water pH, and the addition of a surfactant to the recirculating water. Except for the surfactant addition, the innovations had a negligible effect on increasing the particulate removal. While the surfactant addition increased the particulate removal sufficiently to meet the Federal standards, the increased removal was still not enough to comply with the Maryland standards. Consequently, an electrostatic precipitator is being installed to replace the scrubber.

Besides the scrubber inability to remove the particulate sufficiently, its primary function, the scrubber operation allowed excessive amounts of solids to settle on the scrubber bottom because of the 10-minute retention time along with the low flow velocities of the particulate-laden water within the scrubber bottom. The solids accumulated rapidly until reaching the depth of the scrubber pump suction pipe when a steady-state condition developed with a solids depth of 1 m (3 ft). Since the scrubber has no sludge removal equipment, the sludge had to be removed manually with a vacuum truck during a plant shutdown.

Because of the solid accumulations, the scrubber drain, which is only 75 mm (3 in.) in diameter, clogged rapidly. Then the access manhole had to be opened to clear as well as to drain the scrubber. However, since the particulate-laden water has been discharged directly to the ground surface, this practice is environmentally unacceptable.

The epoxy coating to seal the scrubber water basin deteriorated rapidly and flaked off. As discussed later, the epoxy flakes interfered with the recirculating water system. Although small leaks developed in the foundation, they were quickly repaired. A spider baffle directly below the gas exit corroded and fell out. This baffle, a horizontal disc with vertical radial plates on top to function as flow straighteners, was designed to remove water droplets and to prevent the short-circuiting of gases through the scrubber. Some of the malfunctions of the induced draft fan may have been due to water droplets within the scrubber exit gases.

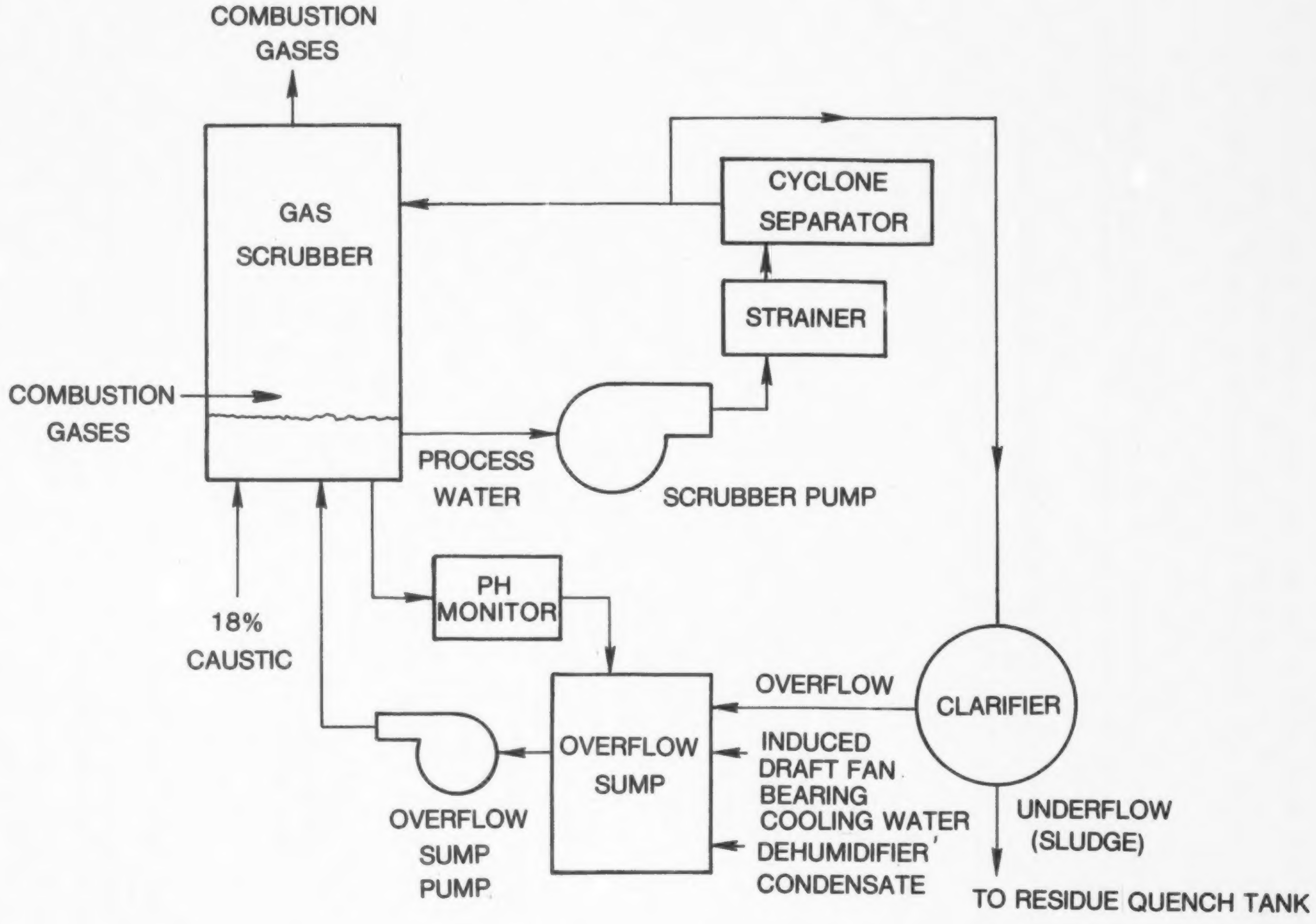

COMBUSTION GASES
GAS SCRUBBER
CYCLONE SEPARATOR
STRAINER
COMBUSTION GASES
PROCESS WATER
SCRUBBER PUMP
18% CAUSTIC
PH MONITOR
OVERFLOW
CLARIFIER
OVERFLOW SUMP
INDUCED DRAFT FAN BEARING COOLING WATER
DEHUMIDIFIER' CONDENSATE
OVERFLOW SUMP PUMP
UNDERFLOW (SLUDGE)
TO RESIDUE QUENCH TANK

Figure 66. Process flow diagram of the gas scrubber system.

The scrubber inlet wall and ceiling refractory was replaced and the new refractory was coated with a water sealer to prevent damage from the inlet water spray. However, after the new refractory had soon deteriorated, it was repaired and then replaced with A. P. Green Steelcom castable refractory and the brick sides were sandblasted and coated with a different water sealer.

Maintenance

While the inlet refractory and outlet baffle required repair and replacement, the gas scrubber itself has required only the preventive maintenance detailed in Table 30.

TABLE 30. GAS SCRUBBER PREVENTIVE MAINTENANCE SCHEDULE

Annually

Zero and calibrate:
- Scrubber water return flow transmitter.
- Scrubber water return flow indicating controller.
- Low water flow alarm.
- Scrubber water to clarifier flow indicating controller.
- Flow transmitter.
- Current to pneumatic converter.
- Scrubber water to clarifier flow valve.

Zero, calibrate, and check operation:
- Scrubber Water pumps discharge pressure indicator.
- Scrubber Water pumps discharge temperature indicator.
- Scrubber gas intake pressure indicator.
- Water to gas scrubber pressure indicator.

Check operation of scrubber pump ammeters.
Check condition of solenoid valve.
Zero and calibrate:
- Level indicating controller.
- High and low level alarms.
- Level switch (differential pressure).

Check condition of purgemeter/flow controller.
Zero, calibrate, and check condition:
- Level control valve.
- Gas scrubber emergency spray control valve.

Scrubber Water Recirculating System

The scrubber water recirculating system continually pumps water from the bottom of the scrubber to the top of the scrubber where a water distribution system sprays fine water droplets to remove the particulate and vapors from the flue gases flowing from near the bottom of the scrubber to the exit duct at the top of the scrubber.

Description

The scrubber water recirculating system consists basically of two centrifugal pumps mounted on a concrete foundation adjacent to the scrubber and the following water distribution system mounted at the top of the scrubber: four horizontal circumferential tier headers with each header connecting to 12 lances and with each lance containing eight or nine nozzles.

The two centrifugal pumps are Goulds Pump Inc., Model No. 3415 horizontal units with a split casing. Driven by a 400-hp motor, each pump has a rated capacity of 13,000 liters per minute (3,500 gpm) at a total dynamic head of 107 m (350 ft) and 1,780 rpm. A three-position switch permits operating either or both of the pumps.

The pumps are connected by a 30-cm (2-ft) diameter schedule 80 steel pipe to the four tier headers which are made of 15-cm (6-in.) diameter schedule 80 steel pipe. Constructed of 4-cm (1.5-in.) diameter schedule 40 steel pipe, each of the 12 lances is approximately 2 m (7 ft) long. Each lance has eight whirljet No. 3/8-BX5525 nozzles made of hardened 440 stainless steel with an orifice diameter of 7.1 mm (0.28 in.). Each of these nozzles has a rated flow of 30 liters per minute (8 gpm) at a pressure of 690 kPa (100 psig). In addition, 8 of the 12 lances has a Fueljet No. 1-H557 nozzle at the end. Also made of hardened 440 stainless steel, this nozzle has an orifice diameter of 9.3 mm (0.33 in.) and a rated capacity of 92 liters per minute (24 gpm) at a pressure of 690 kPa (100 psig).

A water level controller with a bubble-type sensor and a pneumatic valve regulates the flow of city water into the scrubber basin to maintain to maintain a constant 2-m (6-ft) water level in the bottom of the scrubber. An overflow drain in the side of the scrubber ensures that the water does not exceed the 2 m (6 ft) level.

The sprays in the tangential inlet duct for the flue gases are normally supplied with some of the pumped water but with city water when the pumps fail.

Operating Experience

The operating total dynamic head (discharge pressure) for the pumps was lower than the design head. With a given discharge pressure, a pump operates at a corresponding volumetric flow rate; but as the discharge pressure decreases, the flow rate increases and the efficiency decreases. Consequently, since the operating pressure was lower than the design pressure, the pumps operated at extremely high volumetric rates and therefore overloaded the motor. To minimize the motor overloading, the pump discharge valves were partially closed to limit the flow and to increase the discharge pressure.

The abrasiveness, high solids content, and pH variability of the recirculated water cause severe wear and numerous malfunctions of the pumps and the water distribution system. After both pumps had severely corroded, the original bronze fitted shafts were replaced with ones made of 316 stainless steel. In addition, city water was used to cool the pump packing glands. To reduce the pump wear attributed to the pump drawing down the water surface in a cone of depression that allowed cavitation air to enter the pump, a steel plate was installed above the pump suction pipe. Nevertheless, the pumps continued to wear excessively because of the water corrosiveness. Various pump packings, such as teflon and blue afrian asbestoes graphite, were tested, but with little success, to reduce the constant pump leaking.

The lances and nozzles have plugged rapidly, especially those at the end of the tiers where the water distribution terminates since the tiers are not continuous. Since the installed lances and nozzles are difficult to clean, they have to be removed and sent to the maintenance shop for their blowout with compressed air. As corrosion and erosion wore out the lances and nozzles, the nozzles would ultimately slip out of alignment and therefore require tightening because of the criticalness of the spray pattern; some nozzles were so worn that they fell off the lances. Nozzles made of various types of materials were tested, but none proved to be sufficiently corrosion resistant.

Maintenance

Frequent maintenance requirements have included lance and nozzle cleaning and repair, nozzle tightening and replacement, and tightening of the pump packing. A few leaks in the lance flanges required minor repairs.

Among the one-time requirements were the repair of a pump housing, the remachining of a pump rotor, the installation of a new O-ring, and a bearing change. In addition, one of the pump motors had to be repaired because of broken fan blades and a worn shaft. After the fuses had blown when a pump motor shorted to the ground, the high voltage wiring on the motors was replaced.

Table 31 details the scrubber water pump preventive maintenance schedule.

Scrubber Water pH Control System

As the gas scrubber removes particulate and vapors from the flue gases passing through the scrubber, the particulate and water-soluble condensed vapors collect in the scrubber basin water which is continuously recirculated. Since the vapors contain acids, mainly HCL and some H_2SO_4, the scrubber water pH control system adds caustic to the scrubber water to maintain a neutral or slightly basic pH.

Description

The scrubber water pH control system consists of the following: (1) a caustic unloading pump to discharge the caustic from the delivery truck,

TABLE 31. SCRUBBER WATER PUMP PREVENTIVE MAINTENANCE SCHEDULE

Weekly

Check stuffing box, bearings, temperature, and oil level (Paradene 430).
Check pump to motor alignment.
Check pump oil level.

Monthly

Check motor idle, current, and vibration.

Quarterly

Lubricate coupling (LiEP2).

Semiannually

Change bearing oil (Paradene 430).
Pull pump housing and inspect and check clearances if necessary.
Change motor oil (Paradene 415).
Check motor heaters, motor control circuits, and contactors.
Check and megger motors.
Check alarms and interlocks.

Annually

Check calibration of all CO_5 and 86 relays and operation of watt loss relay.
Lubricate motor bearings (Paradene 415).

---

(2) a caustic feed tank to receive, store, and supply the caustics as needed, (3) a caustic feed tank agitator to keep the caustics in the feed tank well mixed and in suspension, (4) a caustic feed pump to pump the caustic from the feed tank to the scrubber, (5) a monitor to sense the pH of the water discharged from the scrubber water recirculating pump, and (6) a controller to regulate the caustic pumped from the feed tank to the scrubber.

Installed in the water treatment building, the caustic unloading pump is a Laborus Pump Co. horizontal centrifugal pump with auxiliary prime. Driven by a 7.5-hp motor, the pump has an open impeller and a casing, both made of cast iron, and a satellite-shaft-trench, grease-lubricated packing gland for abrasion protection. The pump has a design capacity of 550 liters per minute (145 gpm) at a total dynamic head of 12 m (40 ft) of water, a liquid density of 1,280 kg per m^3 (180 lb/ft^3), and a viscosity of 3.0 centipoise.

Adjacent to the water treatment building, the caustic feed tank supplied by the Willard G. Sherman Co. is an enclosed 3.6-m (12-ft) diameter carbon steel cylinder 4.5-m (15-ft) high for a total volume of 47,300 liters

(12,500 gallons). With 61 cm (24 in.) of freeboard, the tank has a working volume of 40,900 liters (10,800 gallons). Four 30 cm (2 ft) wide baffles extending along the inside length of the tank were designed to facilitate the caustic mixing within the tank.

Mounted on top of the caustic feed tank is a propeller-type carbon steel agitator supplied by the Cleveland Mixer Corporation. The caustic feed tank agitator is driven by a 7.5-hp motor.

Also installed in the water treatment building, the original caustic feed pump was a Wilder air-operated, diaphragm slurry pump. This pump has a design capacity of 11.4 liters (3 gallons) per minute at a total organic head of 12 m (40 ft) of water. A recycle line in the pump configuration permits continuous pump operation while the pump intermittently feeds caustic to the scrubber through a pneumatically operated valve in the pump side stream discharge.

The pH monitor, a Unilock electronic sensor, is mounted in a sample line in which scrubber water runs continuously from the discharge piping of the scrubber water recirculating pump to the clarifier overflow sump (described below). As the monitor senses the pH of the scrubber water recirculated to the water distribution system at the top of the scrubber, it transmits a corresponding signal to the pH feed controller.

As activated by the monitor-transcribed signals, the pH feed controller, a Fischer-Porter unit, regulates the setting of the pneumatically operated valve in the discharge side stream of the caustic feed pump which flows to the scrubber.

Operating Experience

After the initial runs with lime as the design caustic material, an inspection of the scrubber revealed that the scrubber water basin had large deposits of sludge and that the nozzles had plugged. Since the sludge accumulations and nozzle plugging was attributed to the lime, an 18 percent sodium hydroxide solution was introduced as the caustic material.

However, since the original Wilden pump was designed for pumping a lime slurry, a pump with a larger capacity was required to handle the sodium hydroxide solution. Consequently, the operation of the Wilden pump was discontinued and a gravity flow line that discharged to the clarifier overflow sump was used until another pump could be procured. Also, the caustic feed tank agitator was not needed since it was intended for the lime that was in a slurry, whereas the sodium hydroxide was in solution. Although much more expensive than the lime, the sodium hydroxide was not successful in eliminating excessive solid accumulations at the bottom of the scrubber.

The newly ordered pump is a Goulds Pump Inc. centrifugal unit driven by a 3 hp motor. The design capacity of this pump is 76 liters per minute (20 gpm) at a total dynamic head of 16.8 m (55 ft) of water. The new pump, however, has not been used since it arrived after the scrubber operation was suspended.

The pH monitor and controller both frequently malfunctioned. Consequently, most of the pH measurements and the corresponding caustic feed adjustments were made manually.

Originally, the sample point for pH monitor was installed in the bed of solids at the bottom of the scrubber. Since the pH content there varied negligibly in comparison to the recirculating water, the monitor was placed in the sample line from the discharge piping of the scrubber water recirculating pump to the clarifier overflow sump. Because of the low velocity flow in the sample line, the water frequently froze during cold weather. In addition, the pH measurements as displayed in the control room readout compared to the manual measurements evidenced the frequent need for calibration adjustments in the monitoring system.

Maintenance

The caustic unloading pump required only minor cleaning and repair. In addition to cleaning, the original caustic feed pump required motor realignment and the installation of new packing. The seam of the caustic feed tank had to be rewelded to stop a leak. The pH monitor required continual maintenance and was removed for cleaning during each scrubber shutdown.

The caustic storage tank preventive maintenance includes annual zeroing, calibration, and operational check of the tank level pressure gauge, the purgemeter flow controller, and the tank temperature indicator.

The caustic unloading pump preventive maintenance schedule is shown in Table 32.

TABLE 32. CAUSTIC UNLOADING PUMP PREVENTIVE MAINTENANCE SCHEDULE

Weekly

Check for leaks, and check grease in oil cup.
Check bearings, and lubrication in the bearing housing.

Monthly

Fill packing grease cup (LiEP2).

Semiannually

Change oil (Paradene 415).
Grease motor (LiEP2).

Scrubber Water Solids Separation System

The scrubber water solids separation system removes suspended solids from the scrubber water to reduce wear in the recirculating system and to prevent the plugging of the water distribution nozzles.

Description

The scrubber water solids separation system consists of the following: (1) a strainer in the direct recirculating water line to remove large particles, (2) a cyclone spearator next in the direct recirculating water line to remove particles ranging from 70 to 100 microns, (3) a clarifier in a bleed-off stream from the direct recirculating water line to remove smaller particles, (4) a clarifier overflow sump, (5) a sump pump to pump the water collected from four sources to the bottom of the scrubber, (6) a clarifier underflow sludge pump to pump the sludge to the residue quench tank and (7) a flocculant feeding system to promote particle coalescing and settling in the clarifier.

The strainer is a basket-type, removable screen that is installed in the direct recirculating water line shortly after the discharge of the recirculating pumps. Also in the direct recirculating water line and after the strainer is the cyclone separator contained in a carbon steel vessel with an approximate 200-liter (53-gallon) volume. The cyclone separator is a Krebes desander with a capacity ranging from 4,500 to 13,250 liters per minute (1,200 to 3,500 gpm).

The bleed-off stream feeding to the clarifier starts at a point in the direct recirculating water line just beyond the cyclone. The clarifier is a 12 m (40 ft) in diameter carbon steel tank with a concrete bottom sloped 1:12 toward the center of the tank. The tank has a 3.4-m (11-ft) depth, 36 cm (14 in.) of freeboard, and an overflow weir on its periphery. The bleed-off stream inlet and the sludge outlet are in the center of the tank. On each side of a supporting and rotating tank-centered pier is a double rake assembly. The upper rake at the water level collects scum, and the lower rake aligned with the sloped bottom pushes and slides the sludge toward the sludge outlet.

The clarifier overflow passes to the sump which also collects condensate from the dehumidifier and the bearing cooling water from the induced-draft fan, both to be discussed later, and the water in the sample line to the pH monitor discussed above. The sump has a 2,500 liter (3,300 gallons) capacity.

The sump pump, which pumps the water in the sump to the bottom of the scrubber, is a Swaby Model 6H-4 vertical unit. The pump impeller and shaft are of iron construction, and the pump bearings are made of lignum vital. Driven by a 20-hp motor, the pump has a rated capacity of 3,700 lpm (975 gpm). An on/off float switch permits intermittent pump operation. If the pump fails, the sump overflow passes to the sewer.

The clarifier underflow sludge pump, which pumps the sludge to the residue quench tank in the kiln fire hood, is a Goulds centrifugal water-sealed unit. Driven by a 3-hp motor, the pump has a design capacity of 380 lpm (100 gpm) at a total dynamic head of 15 m (50 ft) of water. The pump casting and impeller are made of cast iron, and the pump shaft and liners are made of steel. The pump also has a water-flush seal.

Contained within the water treatment building, the flocculant feed system consists of a storage tank, two feed tanks, aspirator feed system to supply dry flocculant to the water line connecting to both feed tanks, and a pump to pump the flocculent from the feed tanks to the clarifier. Each feed tank is a cylindrical vessel with a total volume of 2,100 liters (555 gallons) and a working volume of 1,900 liters (500 gallons). Center-mounted at the top of each feed tank is an agitator supplied by the Clevelend Mixer Corporation. Powered by 1-hp motor, the agitator shafts and their blade propellers are made of stainless steel. Each of the feed tank outlets is valved to the pump to permit pumping the flocculant from either tank. Driven by a 0.5-hp motor, the pump is a Milton Roy positive displacement unit with a design capacity of 5 lpm (1.3 gpm).

Operating Experience

As previously mentioned, a large amount of solids settle within the scrubber. This is the only solids removal before the scrubber water reaches the scrubber water recirculating pumps. When the solids fill the scrubber bottom to the level of the pump suction pipe, a steady state condition occurs and then there is no solids removal before the scrubber water recirculating pumps. This may have caused some of the severe wear the pumps experienced.

Since the strainer is an integral part of the pump discharge line which has no bypass, it can only be cleaned when the pump is turned off during a plant shutdown. During two periods, one when the epoxy coating on the bottom part of the scrubber sloughed off and the other when plastic in the scrubber inlet gas was removed by in the scrubber during cold testing of the kiln, the strainer clogged and subsequently ruptured.

The cyclone separator has removed only 9 kg (20 lbs.) of solids per day with sizes greater than 37 microns. Whenever the separator was shut down without first blowing down the solid accumulations in it, it plugged. Moreover, the blowdown has had to be done manually since the automatic blowdown has never worked well.

Since the bleed-off stream to the clarifier is only about 1,500 lpm (400 gpm), a small fraction of the pump rated capacity of 13,000 lpm (3,500 gpm), the suspended solids concentration in the scrubber basin and consequently in the recirculating water eventually reaches a steady-state condition. The level of solids concentration during this condition is considerably higher than that designed for because of the large amount of particulate in the scrubber inlet gas. Consequently, the nozzle in the water distribution system have been plugging continually. An attempt was made to increase the water flow to the clarifier for greater solids removal, but the small pipes in the clarifier system could not handle the higher flows. When the plant is shutdown, water freezing in the clarifier impedes the clarifier start-up. Also whenever the sludge pipe clogged, the pipe had to be cleared since the clarifier has no drain and there is no other way to drain and clean the clarifier. However, the clarifier has functioned as intended since the suspended solids content in the clarifier overflow has usually been at the design level.

The sump pump has had to be replaced several times because of severe bearing wear. Also the pump has sustained severe corrosion because of the acidic dehumidifier condensate flowing into the sump and the caustic added directly to the sump.

Originally the sludge pump operated intermittently as it was turned on and off by the level controller in the residue quench tank within the kiln fire hood. The off operation allowed the suction line to plug with solids and to freeze during cold weather. Moreover, the line was very difficult to clear because of the inaccessability of the underflow sludge piping. Consequently, a recycle line was installed to permit continuous pipe operation.

The flocculant feed system was used only a short time because it soon became apparent that the suspended solids in the clarifier inlet water would settle rapidly without any flocculant (polyelectrolyte).

Maintenance

The strainer required frequent cleaning, but it could only be cleaned during downtimes because of the lack of a bypass in the pump discharge line. Leaking valves in the cyclone separator had to be repaired frequently. While the clarifier required maintenance only once when a sludge removal rake was sheared, the sump pump has required considerable maintenance: The pump was rebuilt several times; the pump shaft was replaced once and refurbished once; the bearings were replaced twice; and two automatic grease feeders were installed to ensure adequate bearing lubrication. In addition, the pump seal housing was dismantled once for lubrication.

Except for the clearing of the section line, the sludge pump has required only preventive maintenance (Table 33). Since the flocculant feed system operated for the short while, no maintenance information was acquired.

TABLE 33. SLUDGE PUMP PREVENTIVE MAINTENANCE SCHEDULE

Weekly

Check bearing oil level (Paradene 430).

Monthly

Check bearing and seals.

Semiannually

Change bearing oil (Paradene 430).
Grease motor (LiEP2).
Check pumps and alarm.

Annually

Megger Motor.
Zero, calibrate, and check operation of pressure indicator.

The preventive maintenance schedules for the clarifier, flow feed system, and the sump pump are shown in Tables 34 through 36.

Induced-Draft Fan

The induced-draft fan is downstream from the scrubber and adjacent to the scrubber base (Figure 65). The fan produces a draft which draws the kiln combustion products through the kiln, the gas purifier, the waste heat boilers, and the scrubber to the fan itself. Then the fan blows the exhaust gases with sufficient pressure to discharge them through the dehumidifier to the atmosphere.

Description

Driven by a 2,000-hp motor, the fan is a horizontal centrifugal unit with a double inlet. A damper in each inlet box is pneumatically positioned by a Bailey proportioning controller. The fan rotor and casing are constructed of Corten® steel, and the inlet is made of 316 stainless steel. At the suction inlet, the fan has a design flow rate of 7,800 m^3 per minute (275,500 CFM) at 82°C (180°F) and a negative pressure of 75 cm (30 in.) of water.

Sensors on the fan monitor, the bearing oil temperature, and transmit a corresponding signal for the temperature readout in the control room. The fan bearing lubrication oil is water-cooled with city water.

Constructed of Corten steel without a refractory lining, the suction inlet duct is 2.4 m (8 ft) in diameter and extends from the top of the scrubber to the fan housing. Just above the duct inlet at the top of the scrubber, the duct makes a 180° vertical bend to extend vertically toward the ground. Just after the 180° turn, a long steel plate spans the duct interior to straighten the gas flow to the fan housing. As the duct approaches the fan housing, it separates into two ducts, one for each of the two separated sides of the fan housing. The two cones for the duct discharge are installed just above the rotor and the two sides of the fan housing.

Also made of Corten steel, the fan exit duct is 2.4 m (8 ft) in diameter. After extending horizontally from the bottom of the fan housing, the exit duct makes an upward 90° turn. The outside of the duct bend has horizontal slots in a step configuration to allow the removal of water droplets. The area behind the slots in enclosed with Corten steel to contain the air. After the slots, the duct makes another 90° bend to return to the horizontal. Then the duct extends approximately 28 m (92 ft) for its discharge into the dehumidifier.

Operating Experience

The frequent need to rebalance the induced-draft fan because of its excessive vibration had caused numerous shutdowns of the entire processing system. While the various consultants hired by Monsanto and the City could not agree on the factor or combinations of factors causing the excessive vibration, the factors considered as having the highest potential were as

TABLE 34. CLARIFIER PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check power drive chains for unusual noise or vibration.
Check reducers for noise or leaks.
Check agitator for broken paddles.
Check lubrication:
    Agitator reducer.
    (Winter - Paradene 430)
    (Summer - Paradene 475)
    Agitator reducer coupling (LiEP2).
    Winsmith (GMCTDW).
    (Winter - EP5)
    (Summer - EP8)
    Thrust shaft bearing (LiEP2).
    Worm shaft bearing (LiEP2).
    Gear boxes.
    (Winter - EP5)
    (Summer - EP8)

Semiannually

Drain tank.
Check the tank, hose down walls and floor.
Check tightness of all bolts.
Check truss arms and note whether they are sweeping in the same plane.
Adjust tie angles or adjustable back to each truss arm for most effective and equalized cleaning.
Replace any broken or badly bent squeegees.
Refill tank and resume normal operation.
Change oil in agitator reducer.
    (Winter - Paradene 430)
    (Summer - Paradene 475)
Change oil in Windsmith (GMCTDW).
Change oil in gearboxes.
    (Winter - EP5)
    (Summer - EP8)
Change oil in drive chain (Paradene 430).
Grease coupling and drive shaft bearings (LiEP2).
Grease motors (LiEP2).
Check motors and alarms.

Annually

Check and dismantle roller chain coupling.
Megger motor.

TABLE 35. FLOC FEED SYSTEM PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check packing, motor, and housing.
Check lubrication in two reservoirs:
    Diaphram plunger (Paradene 415).
    Gear housing (EP8).

Quarterly

Change oil in both reservoirs:
    Diaphram plunger (Paradene 415).
    Gear housing (EP8).

Semiannually

Grease motors.

Annually

Zero, calibrate, and check operation of:
    Pressure indicator.
    Level pressure gauge.
Check condition of purge meter flow controller.

TABLE 36. SUMP PUMP PREVENTIVE MAINTENANCE SCHEDULE

Weekly

Check oil level in oil cup on cooling water sump pump.

Monthly

Check all motors.
Check for unusual bearing noise and lubricate if necessary.
Check condition and operation of float switches and lubricate (WD-40 and CR226).

Quarterly

Check sump basin sediment level.
Change oil in lubricator on cooling water sump pump.
Change grease in pumps (LiEP2).

Semiannually

Grease motors (LiEP2).
Check motor, condition of float switches, and lubricate (WD-40 and CR226).

Annually

Megger Motor.

follows: (1) buildup of solids on the rotor, (2) erosion of the rotor due to water droplet and/or particulate inpactions, (3) corrosion of the rotor from acidic condensate, (4) unstable fan foundation, (5) resonance of the system's critical and rotational speed, and (6) movement of the rotor on the shaft.

To monitor the vibrations, the fan was instrumented with a sensor to detect the horizontal displacement of the inboard and outboard fan bearings and to transmit a corresponding signal to a readout behind the instrument panel in the control room. The readout assembly activated an alarm if the displacement on either bearing was greater than 0.25 mm (10 mils) and shut down the fan if either displacement was greater than 0.38 mm (15 mils).

After the original rotor wore out, it was replaced with the spare rotor, and XAR-15 stainless steel wear plates were installed on the impinger (concave) side of the vanes to retard corrosion and erosion of the rotor. The wear plates, however, wore out within 2 months, which was shorter than the period for the original blades. In any event, the wear plates were removed to eliminate their possible contribution to the fan imbalance. The corrosion and erosion continued until the fan operating conditions changed from those with a wet gas, as designed, to those with a dry gas, as discussed later.

The potential of the solids buildup on the rotor for being a prime cause of the excessive fan vibration increased greatly after the observation that rotor sandblasting before rebalancing increased the time between the required balances. Consequently, to minimize solids buildup and corrosion, a low pressure (138 kPa, 20 psig), low flow (200 lpm, 52 gpm) water spray system was installed. As pumped from the clarifier, the water sprayed on the rotor contained Calgon CL-69, a corrosion inhibitor. The spray had a negligible affect in preventing the excessive vibration and may have increased it. Later, a test with a high volume, low pressure water spray also produced negligible results. Therefore, either the sprays did not reduce the solids buildup or the solids buildup did not cause the excessive vibration.

Many tests were conducted to analyze the resonance frequency of the fan rotor, fan housing, fan foundation, and other fan components. Most of the consultants concluded from the test results that resonance was not causing the excessive fan vibration.

To isolate the fan from the inlet duct to the fan, an expansion joint was installed in that duct. In addition, the fan bearing oil was changed from the winter to the summer grade since the oil temperature was always above the maximum specified for winter grade oil, and the bearings were rebabitted from the circular configuration to an eleptical one. These modifications, however, had no apparent affect in preventing the excessive vibration.

Then to prevent rotor movement on the shaft, the rotor was welded to the shaft. Since the welding did not prevent the excessive vibration, the rotor movement was eliminated as the sole vibration factor.

After Monsanto's departure, the City made the following modifications and changes which eliminated the excessive vibration: (1) the mass of the fan foundation was increased by connecting the fan foundation to the scrubber foundation, (2) the wet gas scrubber operation was discontinued; consequently, with the fan handling dry rather than wet gas, the gases did not contain the water droplets, but they did have a higher inlet temperature and contains more particulate and acidic vapors and some water, and (3) the original rotor, which had been refurbished, was reinstalled because of the long lead time to procure a new one after the spare rotor had worn out. Figure 67 is a picture of the worn out spare rotor and Figure 68 is a close-up picture showing holes worn through the rotor vane. Since these modifications and changes altered the previous operating conditions, some of the prime potential factors causing the excessive fan vibration could not be isolated and identified.

However, some of the potential excessive fan vibration factors were eliminated in the following course of events. During the Spring of 1977 when the Baltimore Gas and Electric Company did not accept all of the plant's steam production, as usual at this time of the year, the City dumped the unused steam into the scrubber. Then to maintain the scrubber exit gas temperature below 200°C (400°F), the City reactivated the scrubber. But then the fan vibration, which had remained below 0.025 mm (1 mil) for a 6-week operational period, increased within a day to 0.25 mm (10 mils) necessitating the shutdown of the system. Therefore, the stability of the fan foundation, the temperature of the fan inlet gas, and the intrinsic rotor conditions were not the sole causes of the excessive fan vibration since these conditions remained the same when the excessive vibration recurred.

In view of the above, the water droplets and solids buildup would be the principal candidates for determining the cause of the excessive vibration. The actual cause, however, may have been resolved when the fan rotor was cleaned without rebalancing after the previous shutdown since the subsequent fan vibration in the dry gas mode was less than 0.025 mm (1 mil). The solids buildup on the rotor, therefore, may have been the prime cause of the excessive vibration.

After the foregoing system shutdown following the unused steam dumping into the scrubber, the City installed a steam muffler to handle the steam so that the fan could continue to operate in the dry gas mode. Since the muffler installation, there has not been any excessive fan vibration or significant corrosion or erosion.

During normal operation, the fan has operated as designed with sufficient capacity. On one occasion, however, the fan discharge pressure increased substantially with the consequent corresponding reduction of the fan volumetric capacity when the dehumidifier had plugged with solids after the scrubber was turned off. With the scrubber inoperative, the particulate flow to the dehumidifier was higher and there was no condensate flow to keep the dehumidifier clean. After the dehumidifier was cleaned, the discharge pressure was reduced to normal and the fan consequently had sufficient capacity.

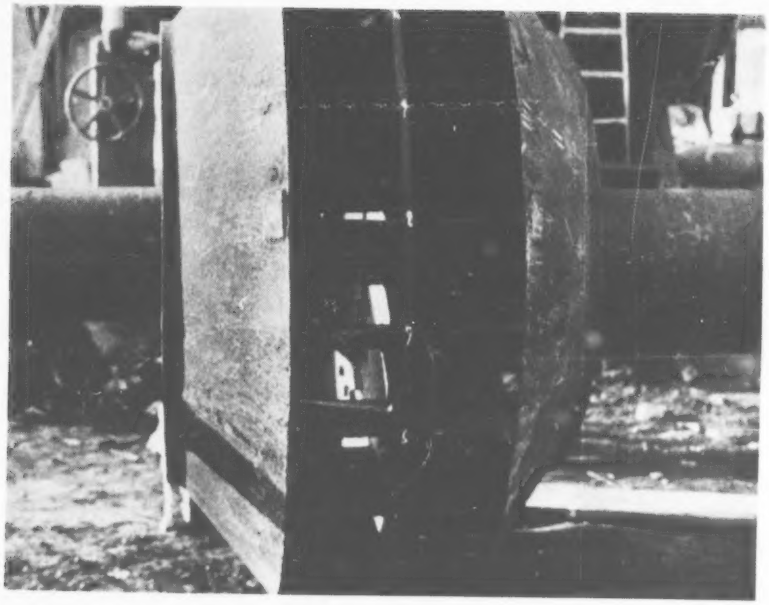


Figure 67. Induced-draft fan rotor.

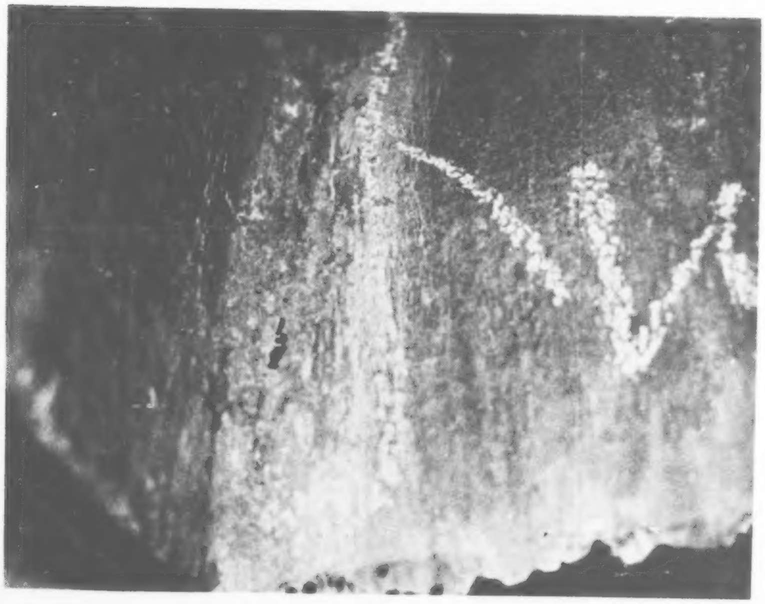


Figure 68. Induced-draft fan rotor vane.

Two conditions had prevented proper damper movement. One condition developed when the damper bushings corroded and locked. To remedy this condition, brass bushings were installed and lubricated well. The second condition developed when the set screws coupling the bushing and the damper shaft had slipped. This slippage asynchronized the dampers and consequently imbalanced the loads on each side of the fan. This condition was remedied by inserting a connecting pin through the damper shaft to the bushing.

Maintenance

The major maintenance item for the fan was the rotor rebalancing which was required every 2 weeks before the scrubber operation was discontinued. A consultant usually did the rebalancing. When the fan was vibrating excessively, the bearings had to be replaced or rebabitted often. Several times the fan had to be cleaned and sandblasted.

The fan housing occasionally required welding to repair holes caused by severe corrosion and erosion. After the drain for the fan housing had frequently plugged, a new drain was installed. In addition, the motor was returned to the factory for tests and repairs to verify that the magnetic center was properly located. The induced-draft fan preventive maintenance schedule is shown in Table 37.

Dehumidifier

The flue gases exiting the induced-draft fan are passed through the dehumidifier (Figure 69) to reduce their moisture content before their discharge to the atmosphere. Consequently, the gas plume is variably reduced depending on the ambient air conditions.

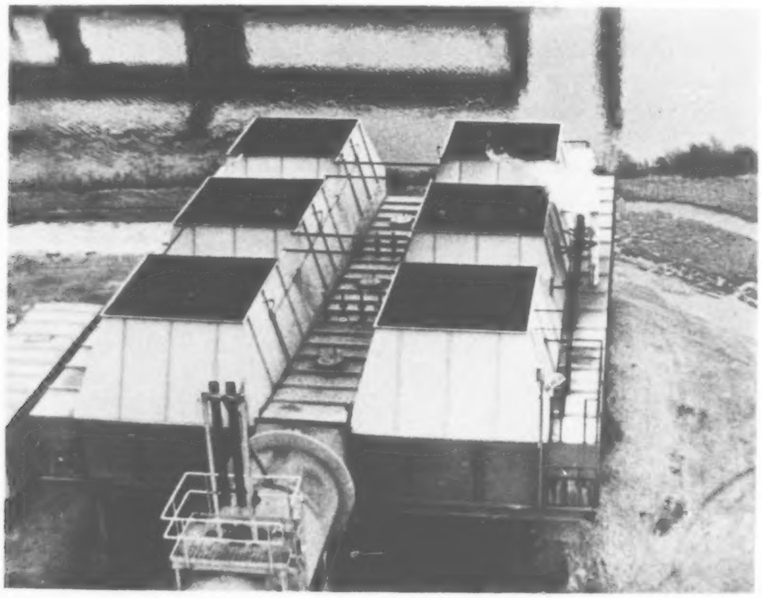


Figure 69. Dehumidifier.

TABLE 37. INDUCED DRAFT FAN PREVENTIVE MAINTENANCE SCHEDULE

Weekly

Check vibration of fan and motor bearings.
Check inlet damper for smooth, balanced operation.
Check lubrication needs.
Check cooling water flow to bearings (15 lpm).
Check motor oil level.
(Winter - Paradene 415)
(Summer - Paradene 430)

Monthly

Check damper linkage, and bearing lubrication.
(Winter - Paradene 415)
(Summer - Paradene 430)
Check motor idle current.
Check RTD's for temperature and temperature spread.

Quarterly

Grease coupling (LiEP2).

Semiannually

Open all access doors.
Inspect impeller and damper for cleaning and reconditioning requirements.
Clean or balance rotor as required to prevent failure.
Disassemble and inspect coupling.
Check bearings.
Pull damper bushings and install grease fittings.
Change shaft bearing oil.
(Winter - Paradene 415)
(Summer - Paradene 430)
Molycote damper bushings.
Change motor oil.
(Winter - Paradene 415)
(Summer - Paradene 430)
Check motor heaters.
Check alarms and interlocks.
Check motor control circuits and contactors.
Check and megger motor.
Check calibration of all CO$_5$ and 86 relays, GFR, differential current trip and operation of watt loss relay.

CONTINUED

TABLE 37. CONTINUED

Annually

High pot motor.
Check bearing high temperature trip and lower position start switch.
Zero and calibrate:
    Pressure transmitter.
    Current to pneumatic convector.
    Pressure indicating convector.
Check condition of purgemeter/flow controller.
Clean, lubricate, calibrate, and check air supply pressure to inlet drive unit.
Zero, calibrate, and check operation:
    Fan discharge pressure indicator.
    Fan intake pressure indicator.
Check operation of ammeter.

Description

The dehumidifier is a 14 m (45 ft) by 18 m (60 ft) carbon steel vessel elevated about 2 m (7 ft) above the ground to allow the vertical flow of ambient air through the vessel. The discharge duct from the induced-draft fan connects with the dehumidifier inlet vestibule which extends the entire length of the dehumidifier and divides the vessel into two equal sides.

On each side of the central inlet vestibule (Figure 70) are three bays connected to an outlet vestibule (Figure 71) which completes the side of the vessel. In each bay, the lower part contains an array of 208 outward cross-flow heat exchanger tubes, and the upper part contains an array of light inward cross-flow distribution pipes. As the gases flow horizontally through the heat exchanger tubes in each bay, the vertical flow of ambient air around the tubes cools the gas and condenses most of the moisture in the gas. Then the gases exiting those tubes rise through a mist collector in the outlet vestible to enter the distribution pipes. As the gases resume flowing horizontally but in the opposite direction, the vertical flow of ambient air around the pipes continues the gas cooling and moisture condensation. Finally, the gases escape through holes in the distribution pipes to blend with the rising air and emerge into the atmosphere. The elevation of the air-gas mixture discharge to the atmosphere is about 9 m (30 ft) above the ground level.

Baffles in the inlet vestibule are designed to equalize the gas flow into each bay. The 208 heat exchanger tubes in each bay are arrayed on equilateral triangle centers of 106 mm (4.2 in.). Constructed of carbon

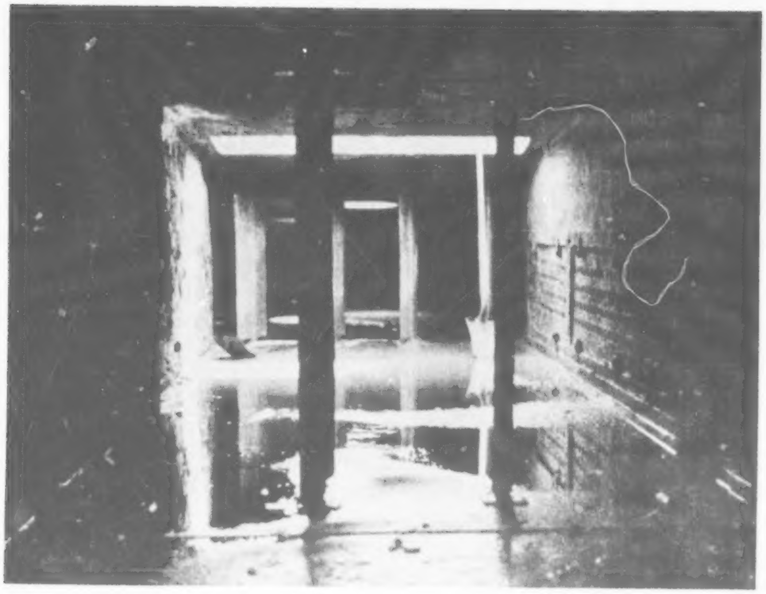


Figure 70. Dehumidifier inlet vestibule.

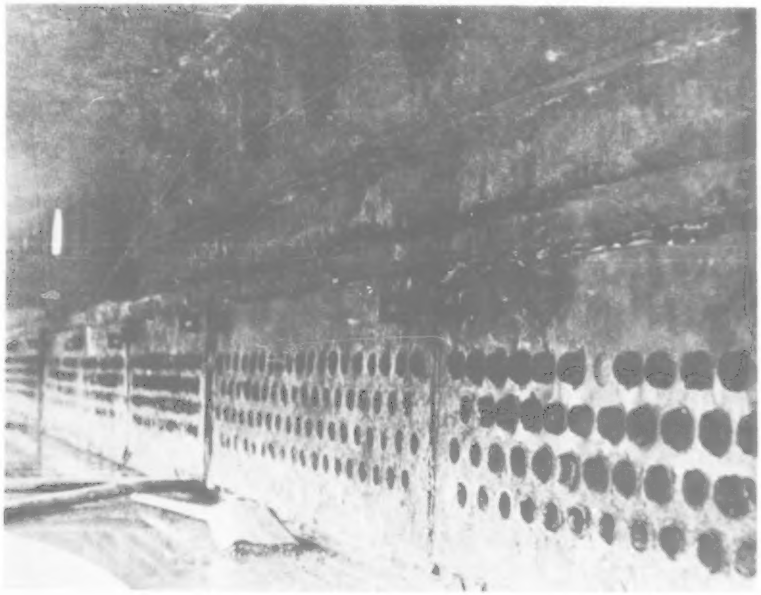


Figure 71. Dehumidifier outlet vestibule.

steel the tubes each have a 60 mm (2.4 in.) inner diameter and a 3.9 mm (0,15 in.) wall thickness. Encircling each tube are 0.5 cm (0.2 in.) spaced carbon steel fins each with a 98 mm (3.8 in.) diameter and a 1.3 mm (0.05 in.) thickness.

The mist eliminator in each outlet vestibule is a 15 cm (6 in.) thick 1.2 m (4 ft) by 5.6 m (18 ft) mesh constructed of stainless steel. The eight distribution pipes for each bay are 41 cm (16 in.) diameter schedule 10 rubber-coated pipes each having nine 114 mm (4.5 in.) diameter holes along the top of the pipe. Both the heat exchanger tubes and the distribution pipes are sloped for the condensate flow to the outlet vestibule. The condensate collecting in the outlet vestibules flows by gravity through a common 100 mm (4 in.) diameter pipe to the clarifier overflow sump.

Below each bay is a 3.7 m (12 ft) diameter, variable blade pitch, fiberglass propeller fan to produce the vertical flow of ambient air around the heat exchanger tubes and the distribution pipes. Each fan is driven by a 30-hp motor and equipped with a high-vibration cut-out switch to prevent the fan being damaged by excessive vibration.

Operating Experience

While the dehumidifier was designed to minimize, not eliminate, the plume it has not been effective when ambient temperatures are below 0°C (32°F), especially when ice forms on the fans. As the ice accumulates, the fans become imbalanced and vibrate above the vibration level of the protective cut-out switch. With the fans off, the density and size of the plume increases markedly. However, the icing could be prevented if the fans were moved to the top of the bays since the exiting gas-air blend would keep the fan temperature above the icing condition.

Originally, the gas distribution to the bays was very poor since most of the flow went to the last bay on each side. Although baffles were installed for better gas distribution, some of the bays are still overloaded and others underloaded. Consequently, the dehumidifier has never attained its design efficiency.

Scaling in the heat exchanger tubes has substantially reduced the heat transfer efficiency. During one period when the scrubber was shut down, the heat exchanger tubes, the outlet vestibules, and the mist eliminators had become plugged with solids. As discussed above, this condition caused a substantial increase in the discharge pressure and corresponding decrease in the volumetric flow of the induced-draft fan.

The low-level dehumidifier discharge (about 9 m, 30 ft above the ground level) is environmentally unacceptable. If the scrubber is operative, the resultant large and dense plume can cause serious fogging and icing conditions on the new interstate highway adjacent to the plant. If the scrubber is inoperative, the resultant high acid concentration in the vapor can be injurious to people and equipment (Figure 72).

The acidic content of the flue gases has severely corroded such dehumidifier components as the vessel shell and the heat exchanger tubes. In particular, the condensate drain lines have corroded through because of the low pH of the condensate (Figure 73).

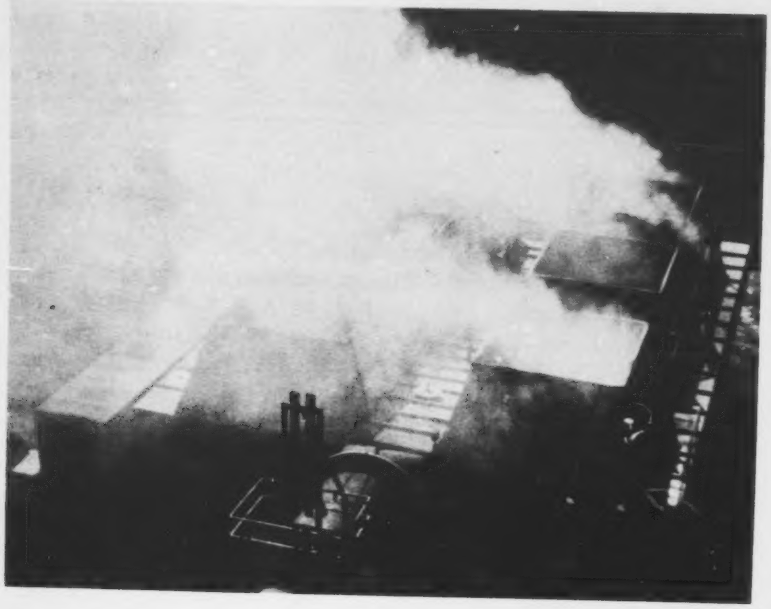


Figure 72. Area fumigation by exhaust gases.

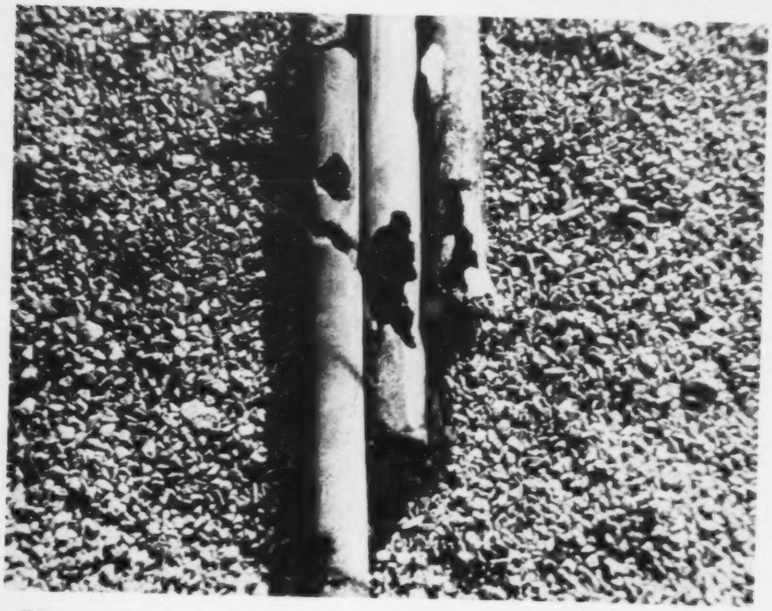


Figure 73. Dehumidifier condensate pipe corrosion.

Maintenance

Except for preventive maintenance (Table 38), the dehumidifier fans have required only new cam roller bearings. After a short operational period, the blade pitch of one of the fans had to be reset. The condensate drain lines were replaced after they had corroded through.

TABLE 38. DEHUMIDIFIER FAN PREVENTIVE MAINTENANCE SCHEDULE

Monthly

- Check reducer oil for sludge or condensation.
- Check oil level in reducers, and check reducers for oil leaks.
- Grease fan bearings (LiEP2).

Semiannually

- Change reducer oil.
  (Winter - Paradene 430)
  (Summer - Paradene 475)
- Grease propellor hubs (Molycote EP2).
- Grease motors (LiEP2).
- Check motors.
- Check alarm and vibration switches.

Annually

- Megger motors.
- Check operation of fan ammeters.
- Zero and calibrate:
  - Remote manual blade pitch control station.
  - Current to pneumatic convertor.
  - Fan blade positioners.
- Check bearing condition of fan blade conditioners.
- Check air lines and air supply pressure to fan blade positioners.

ENERGY RECOVERY MODULE

The energy recovery module, as represented by the shaded areas in Figure 74, recovers the sensible heat in the combustion gases discharged from the gas purifier in the thermal processing module by producing steam to be sold to the local utility company.

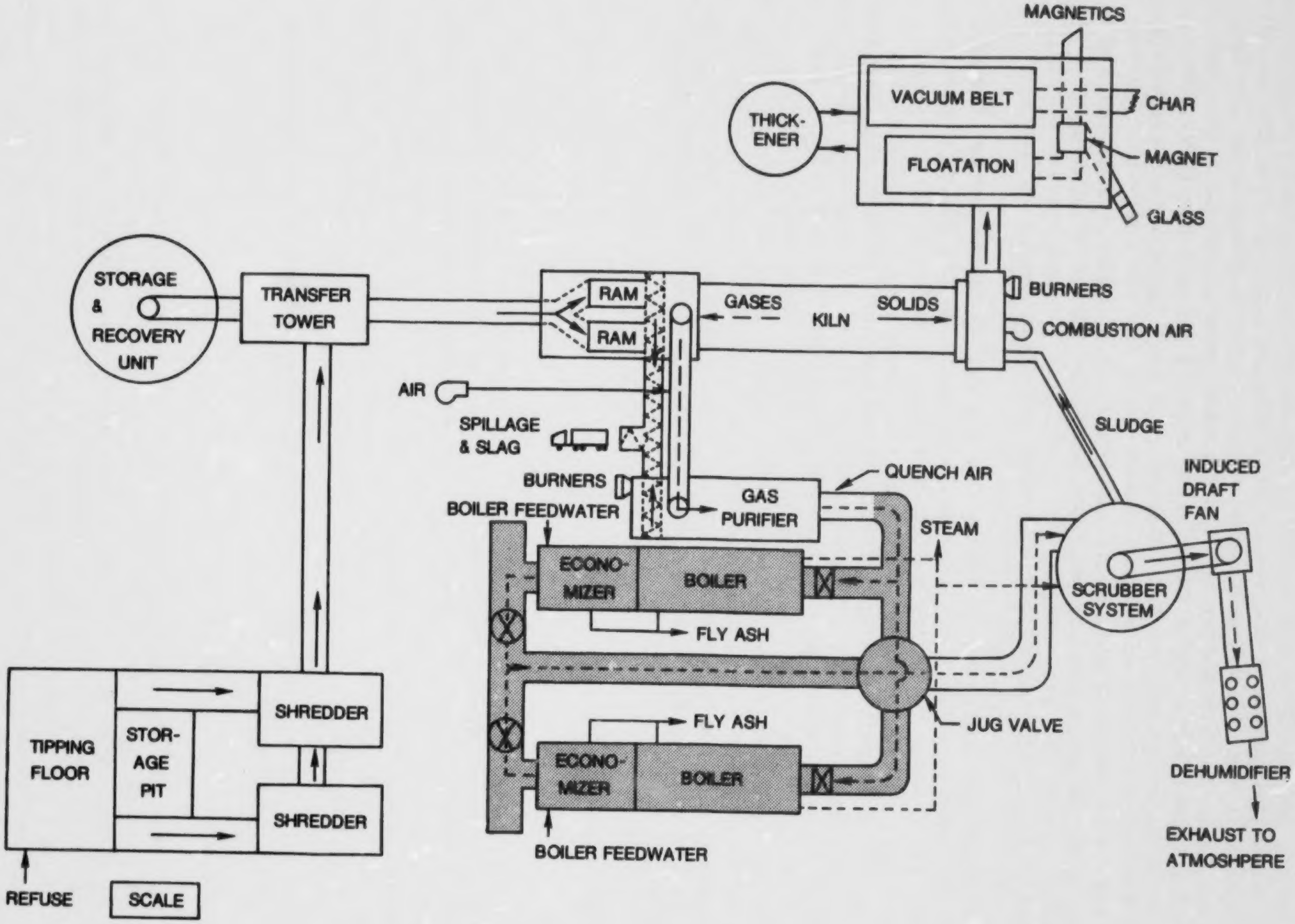

MAGNETICS
VACUUM BELT
CHAR
THICK-ENER
FLOATATION
MAGNET
GLASS
STORAGE & RECOVERY UNIT
TRANSFER TOWER
RAM
RAM
GASES
KILN
SOLIDS
BURNERS
COMBUSTION AIR
AIR
SPILLAGE & SLAG
SLUDGE
BURNERS
QUENCH AIR
INDUCED DRAFT FAN
GAS PURIFIER
BOILER FEEDWATER
STEAM
ECONO-MIZER
BOILER
SCRUBBER SYSTEM
FLY ASH
FLY ASH
JUG VALVE
TIPPING FLOOR
STOR-AGE PIT
SHREDDER
SHREDDER
ECONO-MIZER
BOILER
DEHUMIDIFIER
BOILER FEEDWATER
EXHAUST TO ATMOSHPERE
REFUSE
SCALE

Figure 74. Energy recovery module (shaded area).

Until refractory failures and gas leakage prompted its sealing, a jug valve in the gas purifier and boiler outlet ductwork controlled the gas flow to two parallel waste heat boilers by diverting surplus gas directly to the gas scrubber in the thermal processing model. Initial slagging of the heat exchanger tubes in each boiler and its attached economizer was eliminated by installing quench air dampers in the exit duct of the gas purifier. The boiler-economizer assemblies are equipped with soot blowers to periodically remove ash accumulations on the tube banks and a fly ash collection system which had to be modified because of continued ash plugging throughout the system. Some of the steam produced has had to be wasted by passing it initially through the gas scrubber and then later through a steam muffler, especially during the spring and fall when the steam demand is low.

Although not indicated in Figure 74, the following subsystems for the boiler feedwater treatment are integral components in the energy recovery module: (1) a water softening system to remove from the city water the calcium, iron, magnesium, and other ions that could cause scaling in the boilers; (2) a degasifier system to remove carbon dioxide from the feedwater; (3) a deaerating heater for preheating the feedwater and removing oxygen from it; (4) a chemical system to complete the oxygen removal and prevent the precipitation of the scale--inducing and sludge--forming metallic ions; and (5) two feedwater pumps, a motor-driven pump for boiler startup operation, and a turbine-driven pump for continuous operation after the start-up. Of the feedwater treatment systems, only the degasifier has not operated properly; however, its need has been only marginal because of the low concentration of bicarbonates in the city water.

Water Softening System

In the process of preparing city water as feedwater for the waste heat boilers, the water softening system removes from the water the divalent metallic cations, such as calcium, iron, and magnesium, that would cause scaling the the boilers. The removal consists of exchanging monovalent metallic sodium cations in a synthetic ion exchange resin with the divalent metallic cations as city water flows through a softener tank. When the divalent metallic cation have saturated the resin, they are exchanged with sodium cations when a brine solution is pumped through the tank in the phase of the system cycling to regenerate the resin with the sodium cations.

Upon leaving the softener tank, the feedwater flows to the degasifier for further treatment.

Description

The water softening system consists of (1) three parallel water softener tanks to perform the divalent metallic and sodium cation exchanges, (2) a brine tank into which salt is pumped from a delivery truck and then a properly proportional quantity of water is poured into the tank to prepare the brine solution, and (3) a pump to supply the softener tanks with the brine. The three softener tanks and the brine pump are installed in the water treatment building, while the brine tank is outside of and adjacent to that building.

Supplied by the L. A. Water Treatment Division, each of the three water softener tanks is a Model 206CP3T vertically arranged cylindrical pressure tank. Constructed of welded steel with a baked plastic lining 0.10 to 0.18 mm (4 to 7 mils) thick, each tanks is 1.5 m (5 ft) in diameter and 1.5 m (5 ft) in height with a working volume of 2650 liters (700 gallons), a freeboard volume of 190 liters (50 gallons) and therefore a total volume of 2840 liters (750 gallons). Each tank contains 2265 liters (600 gallons) of synthetic ion exchange resin (LA101) which allows a flow-through capacity of 1700 liters per minute (450 gpm) of water and a feedwater capacity of 1,135,500 liters (300,000 gallons) between the resin regenerations. In addition, each tank is equipped with a low-pressure switch which activates an alarm in the control room when the water pressure drops below a preset pressure, and a water flow integrator which activates an alarm in the control room when a preset volume of feedwater has flowed through the tank.

The operation of the three softener tanks was designed so that two tanks could handle the required feedwater flow while the third was available for the resin regeneration.

The brine tank, which was supplied by the Morton Salt Company, is a Model FG1015 vertically arranged cylindrical tank completely enclosed except for a gooseneck vent at the top. Constructed of fiberglass-reinforced plastic, the tank is 3 m (10 ft) in diameter and 4.5 m (15 ft) in height with a working volume of 31,775 liters (8,400 gallons), a freeboard volume of 2,265 liters (600 gallons) and therefore a total volume of 34,040 liters (9,000 gallons). The tank is equipped with a Morton Model AH water-level indicator.

Also supplied by the L. A. Water Treatment Division, the brine pump is a horizontal centrifugal PVC (polyvinyl chloride) pump. The pump has a rated capacity of 150 liters per minute (40 gpm) at a total dynamic head of 45 m (150 ft) of water. It is operated only when the resin in a softener tank is being regenerated.

Operating Experience

During normal operation when the water flow integrator would sound the alarm indicating that the preset volume of feedwater had passed through a softener tank, the prescribed procedure called for the operators manually initiating the regeneration process which would then proceed automatically. However, whereas the operators were required to check the water hardness once during a shift, they would check the water hardness before each manual initiation of the regeneration.

While the water-level indicator in the brine tank was installed to signal the need for reordering salt, the operators ascertained the need by checking the specific gravity of the brine solution as well as considering the water level because of the unreliability of the indicator functioning and the constant proper proportioning of the water and salt content in the brine tank.

High humidity and condensate in the water treatment building have damaged the electric controls of the water softening system.

The automatic valves in the brine feedlines to the softener tanks have occasionally remained shut because of salt accumulations. Therefore, there have been instances when the softener tanks have resumed the feedwater flow without having their resin regenerated. When there are such salt accumulations and there is need to clear the lines or to clean or repair the pump, the pressurized brine sprays violently at any opening. A pressure relief valve installed in the discharge line of the brine pump would eliminate this condition.

Maintenance

The brine piping has required occasional repairs. The check valve on the brine tank and the brine pump were each replaced once.

The preventive maintenance schedule for the water softeners consist of quarterly checks on the operation of all electrical controls and readout units, all valves, the galloned out alarm, and lubrication of the timer motors.

The brine tank preventive maintenance schedule includes annual checking and cleaning of the flow indicator, solenoid valve, and solenoid valve timer which must also be lubricated.

The brine pump preventive maintenance schedule is shown in Table 39.

TABLE 39. BRINE PUMP PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check bearing temperature (maximum 107°C).
Check pump, stuffing box, and check for leaks.

Quarterly

Grease pump (Pyoplex EP2).

Semiannually

Grease motor (LiEP2).

Degasifier System

After its discharge from the water softening system, the feedwater for the waste heat boilers flows to a degasifier system. In the given order the following processes take place in the degasifier system to remove carbon dioxide from the feedwater: (1) the pH reduction to 5.5 by a sulfuric acid system to reduce the solubility of carbon dioxide before the feedwater enters a degasifier tank, (2) the carbon dioxide removed from the water in the degasifier tank where the feedwater distributes at the top of the tank falls through a lattice-like column (packing) to provide the maximum area for water surface exposure and where atmospheric air vertically blown by a fan through the column serves as a stripping agent to remove the carbon dioxide, and (3) the neutralization of the feedwater by a caustic system which increases the pH to 7.2 as the feedwater is discharged from the degasifier tank.

With the mixture of carbon dioxide and air discharged to the atmosphere, the degasified and neutralized feedwater proceeds to the deaerating heater for oxygen removal before being pumped to the waste heat boilers.

Description

Supplied by the L. A. Water Treatment Division and installed in the water treatment building, the degasifier system comprises three subsystems each with several components: (1) a sulfuric acid system, (2) the degasifier equipment system, and (3) the caustic system.

As mentioned above, the sulfuric acid system decreases the pH of the feedwater to 5.5 in order to reduce the solubility of the carbon dioxide before the feedwater enters the degasifier tank. This system consists of (1) a sulfuric acid storage tank, (2) a sulfuric acid pump, and (3) a degasifier acid controller. The storage tank is a 208 liter (55 gallon) carboy which contains 93 percent sulfuric acid. The sulfuric acid pump, a Milton-Ray Model R-12A simplex positive displacement diaphragm unit, pumps the sulfuric acid from the carboy to the PVC pipe between the water softeners and the degasifier tank. Direct-driven by a 1/4-hp motor, the pump has a cast iron liquid end with special stainless steel trim for acid service. The pump inlet piping is stainless steel and the outlet piping is PVC. The degasifier acid controller pneumatically regulates the flow rate of the sulfuric acid pump according to two signals transmitted to it: a pH signal from a glass pH electrode in a continuous sample line flowing from the degasifier tank to a drain and a flow rate signal from an orifice flowmeter in the degasifier pump discharge line. The degasifier tank, where the carbon dioxide is removed from the feedwater, is a vertically arranged cylindrical tank installed in a pit about 2 m (7 ft) below floor level. Constructed of carbon steel and lined with 5-mm (0.2-in.) thick rubber, the tank is 1.7 m (5.6 ft) in diameter and 4-m (13-ft) high to provide a total volume of 8,700 liters (2,300 gallons). At the top of the tank is a spray header which evenly distributes the incoming feedwater over the entire circular area. The bottom 2.3 m (7.5 ft) of the tank serves as a water surge tank, or wet well, with a 5,100 liter (1,350 gallons) volume to collect and store the degasified feedwater until it is pumped by either of the degasifier pumps. An overflow pipe is 2.7 m (9 ft) above the bottom of the tank, of 0.4 m (1.3 ft) above the normal maximum water level. Between the overflow pipe and the top of the tank is a diameter-wide stripping column. This column provides the maximum area for water surface exposure to the vertically blown atmospheric air which serves as the stripping agent for the carbon dioxide removal from the feedwater. The column is a lattice-like structure of Maspak packing.

Installed on the outside of the degasifier tank and just above the level of the tank overflow pipe, the degasifier fan is a horizontal centrifugal blower manufactured by New York Blower. The fan is direct-driven by a 2-hp motor and has a capacity of 28 m^3 per minute (1,000 CFM) at a pressure of 10 cm (4 in.) of water. In the same pit as the degasifier tank are two degasifier pumps arranged in parallel so that one pump may be operative while the other serves as a spare. Each pump is an Allis-Chalmers Model 4311 horizontal centrifugal pump with a closed impeller. Direct-driven at 1,760 rpm by a 20-hp motor, the pump has a capacity of 1,900 lpm (500 gpm) at a total head of 27 m (90 ft) of water.

As discussed above, the caustic system neutralizes the feedwater by increasing the pH to 7.2 as the feedwater is discharged from the degasifier tank. This system consists of (1) a caustic storage tank, (2) a caustic transfer pump, (3) a caustic mixing tank, (4) a caustic mixing tank agitator, (5) a caustic feed pump, and (6) a degasifier caustic controller. The caustic storage tank is a vertically arranged cylindrical tank supplied by the Willard L. Sherman Company. Constructed of carbon steel, the tank is 1.5 m (5 ft) in diameter and 2.7 m (9 ft) high. With 44 cm (18 in.) of freeboard, the tank has a working volume of 4,160 liters (1,100 gallons) to store 18 or 50 percent caustic, whichever is available on the local market. The tank is equipped with a bubble-type level indicator and thermostatically controlled electric heaters to prevent the caustic solution from freezing. As the means for transferring the caustic solution from the caustic storage tank to the caustic mixing tank, the caustic transfer pump is a Goulds Model 3199 horizontal centrifugal pump. The pump casing, nozzles, and impeller are made of cast iron; the pump shaft and shaft sleeve are constructed of 316 stainless steel; and the mechanical seal is made of BP 171. Direct-driven at 3,500 rpm by a 1.5-hp motor, the pump has a capacity of 110 lph (30 gph) at a total head of 12 m (40 ft) of water.

The caustic mixing tank, supplied by the Willard L. Sherman Co., Inc., was designed to prepare a dilute (18 percent) sodium hydroxide solution from a 50 percent sodium hydroxide solution. Constructed of carbon steel, the tank is 1.2 m (4 ft) in diameter and 2 m (7 ft) high. The tank has a flat bottom and top with a hole in the top to accommodate the agitator. With 40 cm (16 in.) of freeboard, the tank has a working volume of 1,800 liters (475 gallons). The tank is equipped with a bubble-type level gauge. Supplied by the Clevelend Mixer Corporation, the caustic mixing tank agitator is a Model FGB-1/3 vertical propeller agitator. At the top and bottom of the 1.5-m (5 ft) shaft are dual 49 cm (19 in.) diameter propellers each having three steep-pitch marine blades. Constructed of carbon steel, the shaft and impellers are driven at 420 rpm by an electric motor.

The caustic feed pump transfers the sodium hydroxide solution from the caustic mixing tank to the suction line of the degasifier pump for the feedwater neutralization. This pump is a Milton-Ray Model R-100A simplex, positive displacement, diaphragm pump. The pump has a cast iron liquid end with special steel trim for caustic service. Direct-driven at 1,750 rpm by a 3-hp motor, the pump has the capacity for a discharge varying from 0 to 20 lph (0 to 5.3 gph) at a total head of 30 m (100 ft) of water. The degasifier caustic controller regulates the caustic feed pump flow to maintain a 7.2 pH as governed by a pH signal transmitted from a glass pH electrode in a continuous sample line flowing from the degasifier pump discharge to the degasifier tank.

Operating Experience

Although the degasifier system is a type commonly used and an off-the-shelf item, the acid and caustic systems have never operated properly and therefore have been used rarely. However, since the city water has a low concentration of bicarbonates, the need for these systems has generally been marginal at most.

When the acid and caustic systems have been operative, the pH decreases and increases have been excessive because both the caustic and the sulfuric acid feed pumps have too large a capacity, and both the caustic and the sulfuric acid concentrations in the respective solutions have also been too high.

The PVC piping for the acid system developed frequent leaks during the limited system usage.

The check valve on the discharge line of the acid pump was relocated after it allowed water to enter the acid pipe, for the water reaction with the acid caused the pipe overheating which in turn produced a leak. After the check valve was replaced to prevent this condition, the large PVC pipe between the water softeners and the degasifier system developed a leak, unrelated to the check valve replacement, which had to be repaired.

On one occasion when the pit for the degasifier tank and pumps had filled with water and there is no sump pump to discharge such water, the degasifier pump motors sustained water damage and had to be replaced.

In summary, the entire degasifier system has not operated long enough to permit a comprehensive assessment of its operation and maintenance.

Maintenance

The degasifier stripping column and fan have required only preventive maintenance. Annually the degasifier level valve, level controller, high- and low-level alarms and switches, and caustic and degasifier pumps discharge pressure indicators must be zeroed, cleaned, and calibrated. The degasifier fan requires semiannual lubrication (LiEP2).

The maintenance requirements for the sulfuric acid pump have included frequent cleaning and rebuilding, priming of the suction pipe, adjustment of the bypass, relocation of the check valve, and replacement of a length of pipe to eliminate leaks.

The caustic feed pump was repiped twice, and the pump diaphragm was replaced once. The sulfuric acid and caustic feed pumps require weekly checking of the oil level in the air bleed filter reservoirs, and the pump's liquid, and for leaks. Semiannually the oil in the reservoir must be changed (EP5).

The degasifier pumps were realigned after a new coupling was installed, and as mentioned above, the degasifier pump motors were replaced after sustaining water damage. In addition, the bearing and mechanical seal for one of the degasifier pumps was replaced. The preventive maintenance schedule for these pumps are shown in Table 40.

TABLE 40. DEGASIFIER PUMPS PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check bearing temperature (maximum = 82°C):
    If hot, change lubricant.
    If remains hot, then check bearings.

Quarterly

Check grease lubrication for saponification.
Check stuffing box.
Check mechanical seals for leakage.
Lubricate (LiEP2).

Semiannually

Check alignment of pump to motor.
Inspect all piping supports.
Grease motor (LiEP2).

Annually

Remove the rotating element. Inspect for wear and wearing clearances and order replacement parts if necessary.
Remove any deposit or scaling and clean stuffing box.
Measure total dynamic suction and discharge head as a test of pipe connection and compare with past test.
Inspect check valves, especially the one which safeguards against water hammer when the pump stops.

Deaerating Heater

As pumped from the degasifier tank, the softened and degasified feedwater for the waste heat boilers flow to the deaerating heater for oxygen removal. In the deaerating heater, the feedwater is preheated and deaerated by either the steam exhaust from the boiler feedwater pump turbine, high-pressure steam from the boilers, or both. During the deaerating heater processing, the steam condenses to become part of the feedwater, the released oxygen escapes through a vent in the heater, and the preheated and deaerated feedwater flows to either the turbine-driven or the electric-driven boiler feedwater pump to be pumped to the waste heat boilers.

Description

Supplied by the L. A. Water Treatment Division, the deaerating heater is a Model L-N-8.5-260 horizontally arranged cylindrical, spray-type feedwater tank. Constructed of carbon steel, the tank is 2.6 m (8.5 ft) in diameter and 7 m (23 ft) long. The tank has a working volume of 20,400 liters (5,400 gallons) and a total volume of 31,800 liters (8,400 gallons). The valves and inlet section are made of 304 stainless steel.

The tank has three sight glasses to observe the full range of the water level. The operating tank level is set at 28 cm (11 in.) above the centerline. If the level exceeds 38 cm (15 in.) above the centerline, an alarm is activated in the control room. If the level falls below the minimum for the boiler feedwater pumps, a low-level switch shuts off the pumps. The high-pressure steam entering the tank is regulated by a steam control valve whose positioning is a function of the tank pressure. Also the feedwater entering the tank is regulated by a Fischer-Governor Co. No 657-Ed pneumatically operated water-level control valve to maintain the water level at a 28 cm (11 in.) above the centerline.

To protect the boilers, an emergency waterline with a manual valve directly connects the city water supply to the deaerating heater if the feedwater piping or equipment fails.

Operating Experience

Since the deaerating heater is standard equipment typical of that used in most boiler facilities, most of the malfunctions have been due to piping leaks, especially those induced by freezing conditions. Consequently, the tank placement in a protected environment should be considered.

Although the tank was designed for an outlet temperature of 121°C (250°F) and an internal pressure of 64 kPa (10 psig), the operating temperatures and pressures have generally been about 105°C (220°F) and 35 kPa (5 psig).

To prevent water hammering when the high-pressure steam control valve was opened causing the entering steam to rapidly evaporate the condensed steam in the line, a 2.5-cm (1-in.) bypass steam line was installed around that valve.

Maintenance

The water-level control valve for the feedwater flow into the tank and the actuator in the modulating high-pressure steam valve were replaced. Sight glasses, valves, and pipes broken by freezing were also replaced.

Table 41 presents the preventive maintenance schedule for the deaerating heater.

TABLE 41. DEAERATING HEATER PREVENTIVE MAINTENANCE SCHEDULE

Annually

Zero and calibrate level valve, intake from degasifier.
Check operation of solenoid.
Clean and calibrate:
  Magnetic alarm switch.
  Level controller.
  Steam pressure valve from boilers.
  Pressure indicating controller.
Zero, calibrate, and check operation:
  Temperature indicator gauge.
  Feedwater pressure indicator.
  High water level switch.
  Low water level switch.
  High and low water level alarms.

Boiler Feedwater Chemical System

The boiler feedwater chemical system supplies two chemical solutions to the feedwater: in the deaerating heater a sodium sulfite solution to ensure complete oxygen removal from the feedwater and thereby to prevent boiler corrosion, and in the boilers a chelate solution prepared with ethylenediaminetetraacetic acid (EDTA) to prevent the precipitation of any divalent metallic cations thereby minimizing scaling and sludge formation.

Description

Supplied by the Milton-Ray Co. and installed in the water treatment building, the boiler feedwater chemical system comprises two subsystems: one for the sodium sulfite solution and the other for the chelate solution. Each subsystem consists of a tank, an agitator, and a pump.

The sodium sulfite tank is a vertically arranged cylindrical tank with a flat bottom and a flat hinged top. Constructed of carbon steel and mounted on legs, the tank has a 76-cm (30-in.) diameter and a 46-cm (18-in.) height for a total volume of 190 liters (50 gallons) with 14 cm (5 in.) of freeboard. Mounted to the tank by a portable clamp, the sulfite solution agitator consists of a vertical 316 stainless steel shaft and propeller driven by a 1/4-hp motor. The pump to transfer the sulfite solution from the tank to the deaerating heater is a Model R-120A simplex, positive displacement, proportioning diaphragm pump with an adjustable discharge and a cast iron liquid end. Driven at 1,760 rpm by a 1/4-hp motor, the pump has a rated capacity of 23 lph (6 gph).

The chelate tank is a vertically arranged, cylindrical, polyethylene tank with an open top and a flat bottom. Mounted on legs in a metal frame, the tank has a 69-cm (27-in.) diameter and a 107-cm (42-in.) height for a total volume of 400 liters (105 gallons) with 5 cm (2 in.) of freeboard. All piping, valves, and strainers are PVC. Also mounted to the tank by a portable clamp the chelate solution agitator is a Model 102-0115-116 agitator. Its shaft and impeller are made of 316 stainless steel and are driven at 1,760 rpm by a 1/4-hp motor. The pump to transfer the chelate solution from the tank to the deaerating heater is a Model FR 231-A-78 duplex, positive displacement pump with an independent adjustable flow and a 316 stainless steel liquid end. The pump is driven at 1,140 rpm by a 1/2 hp motor, and the flow capacity of each head is 60 lph (16 gph) at a pressure of 2,275 kPa (330 psig).

Operating Experience

The solutions for each tank are prepared daily by manually feeding the dry chemicals and water into the respective tank and then mixing the solutions with the agitators. The solutions are pumped continuously throughout the rest of the day. Since the system components are standard units typical of those used in most boiler facilities, their performance is generally the same as the conventional norm. Except for occasional freezing or plugging of the chelate lines, the boiler feedwater chemical system has operated well.

Maintenance

After a short operational period, the motor for the sulfite tank agitator had to be replaced. The piping for both pumps had to be frequently repaired because of numerous leaks. The chelate pump fractured a pressure plate which had to be replaced; the pump itself had to be repaired after it jammed; and the pump strainer was replaced.

As preventive maintenance, the sulfite and chelate pumps required weekly checking of the liquid ends for leaks, and the lubrication and oil level in the reducer. Semiannually the oil in the reducer required replacement (EP5).

The preventive maintenance schedule for all the agitators including the sulfite and chelate agitators is shown in Table 42.

Boiler Feedwater Pumps

The boiler feedwater pumps pump the pretreated and preheated feedwater from the deaerating heater and through the economizers to the waste heat boilers.

TABLE 42. AGITATOR PREVENTIVE MAINTENANCE SCHEDULE

Quarterly

Check reducer for vibration, leaks, or noise.
Check motor for vibration or heat.
Check reducer gear box lubrication on both floc feed tank agitator and caustic tank agitator (LiEP2).
Check reducer gear boxes on chemical feed tank agitator.
(Winter - EP5)
(Summer - EP8)

Semiannually

Check reducer for vibration, noise, leaks.
Check motor for vibration or heat.
Change oil in chemical feed tank agitator reducer gear box.
(Winter - EP5)
(Summer - EP8)
Lubricate shaft bearing on chemical feed tank agitator (LiEP2).
Grease all motors (LiEP2).

Description

There are two boiler feedwater pumps: a startup pump also functioning as a spare which is driven by a 200-hp motor, and a post-startup continuously running pump which is driven by a steam turbine. Each pump is a Peerless Model TUT-9 7.5 cm (3 in.), four-staged, horizontally split case, centrifugal pump with mechanical seals, water-cooled stuffing box, and a bearing housing directly coupled to the drive source. Also each pump has a design capacity of 2,120 lpm (560 gpm) at 3,500 rpm and a total head of 320 m (1,050 ft) of water.

The steam turbine is a Cuppus Model TP22L horizontal unit equipped with an automatic, differential pressure, steam-feed governor set to maintain the feedwater discharge pressure at 587 kPa (85 psig) above the steam pressure. A horizontal separator installed in the steam inlet line to the turbine removes all solid and liquid impurities. The separator shell is constructed of carbon steel, and the separator element is made of 304 L stainless steel.

The following built-in provisions maintain the feedwater flow to the boilers and protect the pumps. The two pumps are interlocked so that the discharge pressure of the turbine-driven pump falls below 2,650 kPa (385 psig), the electric-driven pump is automatically started. If the turbine speed exceeds the rated speed by 20 percent, safety trip mechanism stops the steam flow to the turbine. In addition, a relief valve prevents excessive back pressure in the turbine case.

Operating Experience

As designed, the electric-driven pump was to operate at start-up and until the steam main would be hot and up to pressure. Then the turbine-driven pump could be started and the electric-driven pump turned off. However, the electric-driven pump has been operated much more than originally planned because of the following: First, since the plant operation was very irregular during the demonstration period, the steam main was often not up to temperature and pressure long enough to permit starting the turbine-driven pump. And second, the turbine-driven pump was shut down for repairs much of the time because of the diaphragm failures which occurred when the electric pump was started and the pressure at the discharge of the turbine-driven pump was so reduced that the diaphragm could not withstand the excessive differential pressure across it.

Both pumps have vibrated excessively and sustained minor leaks at the seals. The feedwater valves have had to be throttled back because of valve erosion due to low-flow conditions. Consequently, to reduce the erosion, the valves were coated with stellite, a hard, wear-resistant, and corrosion-resistant alloy.

Maintenance

Shortly after the initial start-up, the electric-driven pump was returned to the factory for major repairs when an inspection of the pump revealed that the impeller had broken into several pieces. After the repair, the pump has required only minor maintenance such as alignment, repair of a leak in the bearing cooling water lines, and replacement of set screws in the seal ring with stainless steel set screws after the original set screws had eroded.

Although the diaphragm in the governor of the turbine was replaced several times, as mentioned above, most of the maintenance on that pump involved its piping. In addition, the turbine-driven pump had to be cleaned once.

The preventive maintenance schedule for these pumps is shown in Table 43.

Waste Heat Boilers and Economizers

During normal operation, the gas purifier discharge gases are cooled with ambient air entering the duct through quench air dampers and then enter the two parallel waste heat boilers, where their sensible heat is recovered

TABLE 43. FEEDWATER PUMP PREVENTIVE MAINTENANCE SCHEDULE

Weekly

Check mechanical seal, bearings, turbine condition, and turbine oil level (Paradene 430).

Monthly

Change oil in turbine.
Turn turbine lube screw on packing one half turn.

Quarterly

Grease bearings (LiEP2).
Lubricate coupling on turbine.

Semiannually

Grease motor (LiEP2).
Check motor alarm and interlocks.
Check automatic start switch.

Annually

Megger motor.
Zero, calibrate, and check operation of feedwater pump discharge pressure indicator.

in the form of steam. Upon exiting the boilers, the gases flow through the economizers (one attached to each boiler without intermediary ductwork) to preheat the boiler feedwater and then combine to proceed to the gas scrubber.

Fly ash depositing on the boiler and economizer heat exchanger tubes as the gases pass through are removed by the steam jetted from built-in soot blowers. At the bottom of the boilers and economizers, below the tube banks, are hoppers into which the ash falls for its discharge into the fly ash collection system. Counter to the gas flow, the feedwater passes through the economizers to the boilers.

The boiler-produced steam has been sold to the Baltimore Gas and Electric Company, used within the plant, and vented to the gas scrubber. The steam delivered to the Baltimore Gas and Electric Company flows through a steam main to the Ledenhal Station which is about a mile away from the Landgard plant. At this station, the delivered steam passes through a steam entrainment separator to remove water, scale, and other nongaseous impurities before it enters the distribution line for the steam routing to various remote sites.

Description

The two parallel waste heat boilers and economizers, manufactured by Erie City, are installed beside the gas purifier. The schematic drawing in Figure 75 shows the boiler and economizer configuration. Each of the boilers is designed to produce 56.7 Mg per hr (125,000 lb. per hr) of saturated steam at a pressure of 2,277 kPa (330 psig).

In the conventional arrangement, the boiler consists of a steam drum at the top and center of the boiler shell and two mud drums at the bottom and respective sides of the boiler shell. With the three drums aligned along the entire length of the boiler, a bank of heat exchanger tubes in a partial oblique but generally vertical pattern connects the steam drum with the two mud drums. Both the drums and the tubes are constructed of carbon steel.

The steam drum has a 121 cm (48 in.) inner diameter and a total volume of 13,200 liters (3,500 gallons). With a normal operating water volume of 7,750 liters (2,000 gallons), the steam drum has the optimum surface area for water evaporation into steam and an ample water depth to ensure the continuous water supply to fill the tubes and the mud drums. Each mud drum has an 86-cm (34-in.) inner diameter and a total volume of 6,600 liters (1,950 gallons). Suspended solids accumulating in the mud drums are periodically removed by discharging part of the mud drum water to the blowdown system. Consisting of tubes each with a 51-mm (2-in.) outerdiameter, the bank of heat exchanger tubes has a total water volume of 12,400 liters (3,250 gallons) and provides 940 m^2 (10,000 ft^2) of heat exchange surface area between the boiler water and the gas purifier exit gases. The gases make a single pass through the tube tank.

For the single gas pass through the boiler tubes, the tube bank is enclosed at the top and on the sides by a duct with an airtight refractory lining (shell). Below the bank of boiler tubes are refractory-lined hoppers to collect and discharge the fly ash removed from the tubes.

Each boiler is equipped with such accessories as safeties, vents, and blowdown valves; pressure and water gauges; an internal steam purifier; a feedwater distribution pipe; automatic soot blowers; and an electric system to remotely read the boiler drum water level.

The boiler shell is insulated with fiberglass to prevent heat loss, and the insulation is covered with painted steel sheet metal to protect it from the weather.

Upon exiting the boiler, the gases make a double pass through the economizer. The economizer is a bank of heat exchanger tubes, each with a 51-mm (2-in.) outer diameter. Each economizer has a total water volume of

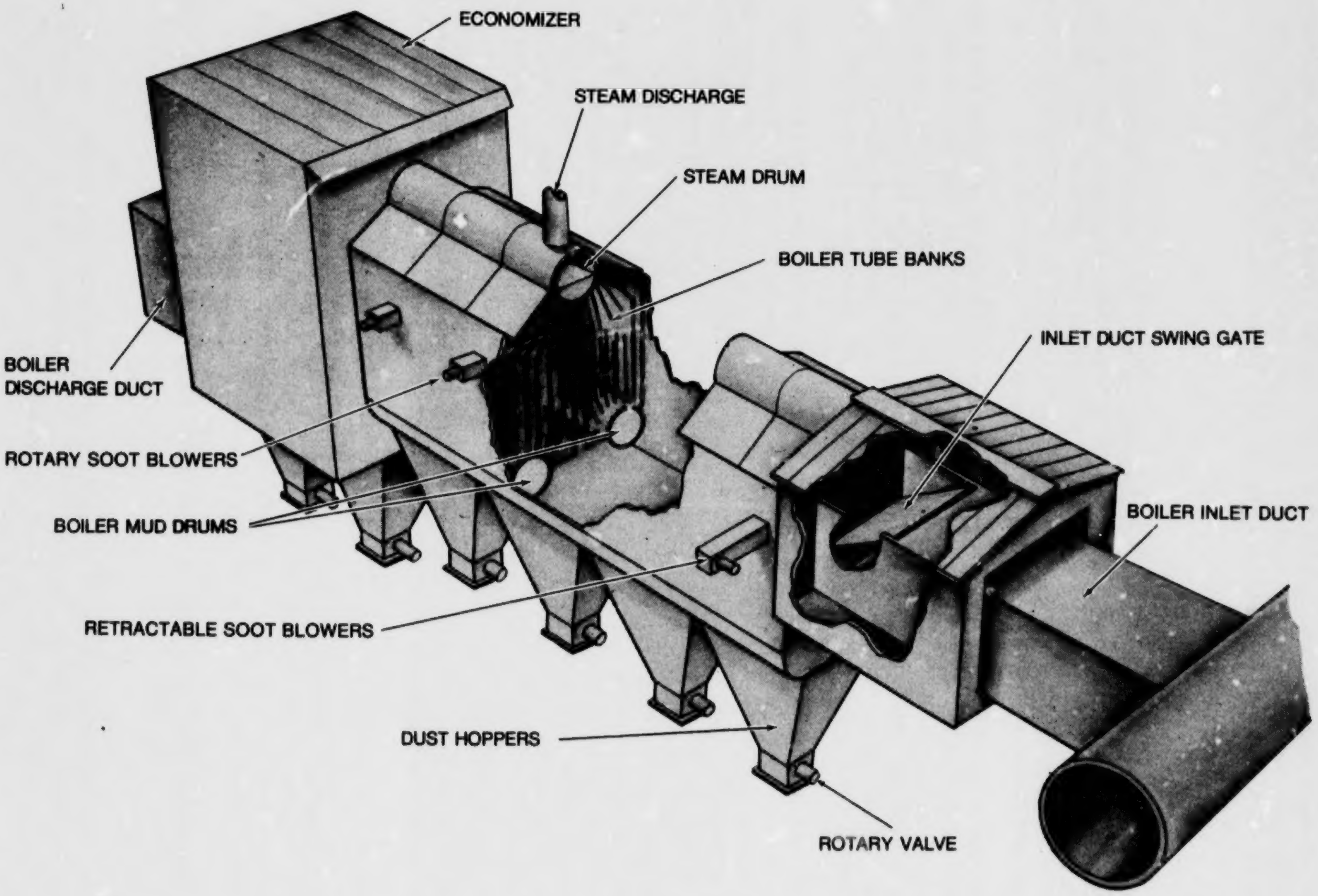

ECONOMIZER
STEAM DISCHARGE
STEAM DRUM
BOILER TUBE BANKS
INLET DUCT SWING GATE
BOILER DISCHARGE DUCT
ROTARY SOOT BLOWERS
BOILER MUD DRUMS
BOILER INLET DUCT
RETRACTABLE SOOT BLOWERS
DUST HOPPERS
ROTARY VALVE

Figure 75. Schematic of waste heat boilers.

7,560 liters (2,000 gallons) and provides 710 m^2 (7,650 ft^2) of heat exchange surface area between the feedwater and the gases. Fly ash hoppers, similar to those in the boiler, lie below the tube bank. In addition, the ductwork for the gas flow through the economizer and the insulation for the economizer shell are similar to those for the boiler. The gases exiting the two economizers combine and then flow through ductwork to the gas scrubber.

The steam produced in each boiler combine to be; delivered to the Ledenhal Station of the Baltimore Gas and Electric Company, used within the Landgard plant, or vented to the gas scrubber, as mentioned above. When the steam is not used, it is directed to the gas scrubber through a vent consisting of an insulated steel pipe with a manual valve. When the steam is sold to the Baltimore Gas and Electric Company, it is delivered through a steam main to the Ledenhal Station, which is about a mile away from the Landgard plant. Designed for a steam flow of 91 Mg per hr (200,000 lb. per hr), the steam main is an insulated steel pipe with a 30-cm (12-in.) diameter. Lying mostly underground, the steam main from the Landgard plant to the Ledenhal Station has ball-type expantion joints and seven fairly evenly separated condensate traps, each with a manhole access. At the Ledenhal Station, the steam passes through a steam entrainment separator to remove water, scale, and other nongaseous impurities before the steam enters the distribution line for the steam routing to various remote sites. The steam entrainment separator is a Wright-Austin Type 31LS horizontal, line-type separator with a carbon steel shell and a 304 stainless steel separator. The line size for the separator is 40-cm (16-in.) schedule 40.

The steam-jetting soot blowers to remove the fly ash accumulating on the heat exchanger tubes in the boilers and economizers are of three types--all manufactured by Copes-Vulcan. Of the five evenly spaced soot blowers along the side of each boiler, the first three from the gas inlet end are Model T20E retractable units. When operated, this model ejects steam to dislodge the soot while both traversing and rotating into and out of the boiler tube bank. The transverse and rotational speeds are both 1 mpm (3.3 fpm). The last two soot blowers on the side of each boiler are each automatic rotary-type units. Since these two soot blowers are stationary and remain in a fixed position within the tube bank, they rotate only while ejecting steam. The four soot blowers evenly spaced along the side of each economizer are all of the same type, namely, Model D-5 manual, rotary-type unit. Since this unit is also stationary, it similarly rotates only while ejecting steam. While the automatic rotary-type model is driven by a motor, the manual rotary-type model is operated by pulling a chain.

Operating Experience

As previously discussed, the slagging of the boiler tubes had been eliminated by installing the quench air dampers in the exit duct of the gas purifier. The ambient air entering the ducts has cooled the gas entering the boiler inlet ducts from 1100°C (2000°F) to 900°C (1600°F) which is well below the ash fusing temperature of 1150°C (2100°F). In addition, the previous slagging had also plugged the fly ash hoppers and jammed the rotary valves in the bottom of these hoppers.

Research conducted by Vaugh, Krause, Miller, and others of Battelle Laboratory prompted the concern that fly ash accumulating on the first few rows of the boiler tubes (Figure 76) could cause tube corrosion, especially since the intensity of the corrosion is a function of higher temperature. However, measurements of these tubes showed no significant decrease in their outer diameters (Table 44) or the tube wall thickness (Table 45). Moreover the fly ash buildup on these tubes would not appreciably decrease the heat transfer since the tube area involved is only a small fraction of the total heat transfer area. In any event, the fly ash buildup on these tubes could be minimized by installing a soot blower closer to the boiler gas inlet. Insofar as the investigation or treatment of the interior tubes is concerned, there is no access way or method to inspect or manually clean their fire sides.

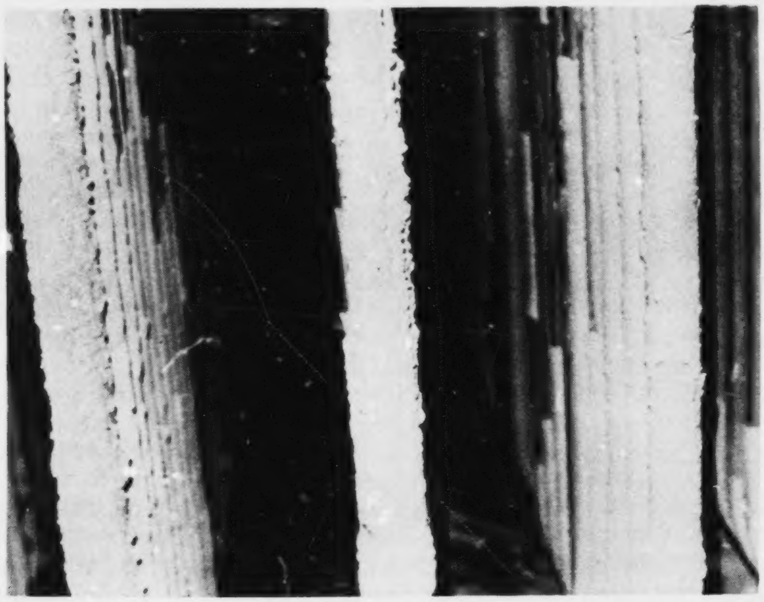


Figure 76. Fly ash accumulating on the first row of boiler tubes.

TABLE 44. MICROMETER MEASUREMENTS OF BOILER TUBES*

	Outside diameter perpendicular to flow (mm)	Outside diameter parallel to flow (mm)	Outside diameter original (mm)
Boiler No. 1	50.52	50.62	50.8
	50.67	50.45	50.8
	50.54	50.64	50.8
Boiler No. 2	50.58	50.49	50.8
	50.52	50.43	50.8
	50.33	50.52	50.8

* June 8, 1977

TABLE 45. BOILER TUBE CORROSION*

	Thickness Boiler No. 1 (mm)	Thickness Boiler No. 2 (mm)	Thickness original (mm)
	3.56	3.30	3.43
	3.43		3.43
	3.68		3.43
Inlets	3.43		3.43
	3.94		3.43
Economizers	4.32 - 4.45		3.81
	4.06		3.81

* Unpublished Monsanto Date, October 22, 1976.

Because of the varying mass rate of the shredded refuse fed to the thermal processing module, it was difficult to produce steam with a constant rate and pressure. Even when the thermal processing module operated at the maximum capacity of 38 Mg per hour (42 tph), the boilers did not reach the design steam rate of 91 Mg per hour (200,000 lb. per hour). This inability can be attributed to the ambient air entering the quench air dampers the high heat losses through the gas purifier wall, the gases bypassing the boilers through the jug valve, and the reduction of the fuel oil burned in the kiln.

In addition to the steam-producing deficiencies within the Landgard plant, a substantial amount of the steam discharged into the main to the Ledenhal Station has been lost en route because of the high ground water level which results in much of the steam main and the condensate trap manholes being under water. In addition, some steam has leaked through the main expansion joints. Moreover, although the amount of steam produced is much less than that designed, the Baltimore Gas and Electric Company has had insufficient need in the spring and fall to purchase all the steam produced. Even during periods of high steam demand, the operators at the Ledenhal Station have generally been unwilling to adjust their steam production so that all steam produced at the Landgard plant could be passed through the steam main to the station.

When the steam was directed to the Ledenhal Station, it had to be throttled considerably since the pressure in the Ledenhal steam main is only 1,035 kPa (150 psig) while the design pressure of the steam generated at the Landgard plant is 2,277 kPa (330 psig). When the automatic valve to throttle the steam flow occasionally malfunctioned, a safety valve opened to relieve the explosive steam pressure. Moreover, some of the safety valves were installed facing down. Obviously, steam emitted from such valves could have seriously injured personnel in the vicinity.

When the steam could not be delivered to the steam main or used within the Landgard plant, it had to be vented to the gas scrubber. But as discussed previously, the vented steam caused the resumption of the excessive vibration of the induced-draft fan. Consequently, the steam muffler was installed to permit wasting the steam without passing it through the gas scrubber.

Initially, when there were no boiler pressure readouts in the control room, the operators had to read a boiler-mounted dial gauge to check the pressure in each boiler. While remote pressure gauges were later installed in the control room, the operators questioned their accuracy.

During the winter, the small water lines frequently froze, especially the sampling line. In addition, the blowdown lines of the mud drums froze occasionally, particularly during the periods between blowdowns when there was no flow in the lines.

Since the main steam valves have been difficult to open, an equalizing line should be installed around such valves to permit easier opening. In addition, many of the small isolation valves have a maximum pressure rating below the design boiler pressure.

When the soot blowers are operating, steam condensing within the blowers cause water hammering, which could be eliminated by installing drain lines in the blowers.

Frequently, during standby operation and when the shredded refuse flow to the thermal processing module has been erratic, there has not been enough steam pressure for the soot blowers in their once-per-shift operation. An access platform was installed on the side of each economizer to permit easier manipulation of the chains rotating the soot blowers.

The fly ash hoppers in the boilers and economizers have frequently plugged because of the large amount of ash removed from the heat exchanger tubes during each soot blowing and the bridging of agglomerated fly ash lumps across the hopper walls. To facilitate clearing away the ash accumulations in the economizer hoppers, pipes were installed in the sides of the hoppers to permit horizontal rodding. However, the inadequacy of this method proved that the ash could be effectively cleared only by removing the rotary star valve assembly and rodding the hoppers vertically. The hopper plugging could possibly be eliminated by making the hopper outlets larger and/or by operating the soot blowers more often.

Maintenance

Most of the boiler and economizer maintenance requirements were for single or occasional malfunctions. A few times, the blowdown and steam regulator valves became locked in position and had to be freed and the tsight glass on a water level gauge had to be replaced. The soot blower fuses were replaced frequently. One of the economizers required a new main valve. After the feedwater modulator valves were severely worn due to the high velocitils caused by their throttling, each valve was repaired by replacing the piston and rebuilding the seat.

Table 46 details the boiler preventive maintenance schedule.

Boiler Ducts and Jug Valve

The jug valve was designed to control the gas flow from the gas purifier to the boilers, economizers, and gas scrubber by diverting the unneeded portion of gas directly to the gas scrubber.

Description

Figure 74 shows the relative positions of the gas purifier exit duct, the jug valve, the boiler inlet and outlet ducts, and the gas scrubber inlet duct--all briefly described as follows: Midway between the two boiler inlet ducts, which connect to the gas purifier exit duct, is the jug valve which is a movable circular disk within a vertical cylinder. The vertical cylinder with its bottom open to the top of the gas purifier exit duct connects the horizontally aligned boiler outlet and scrubber inlet ducts which are elevated above the gas purifier exit and the boiler inlet ducts (Figure 77).

TABLE 46. BOILER PREVENTIVE MAINTENANCE SCHEDULE

Weekly

Check gear box oil level on retractable soot blowers.

Monthly

- Check all rotary gates for noisy operation.
- Lubricate "PN" rotary gates:
  - Grease bearings (LiEP2).
  - Check oil level in reducer.
  - (Winter - EP5)
  - (Summer - EP8)
- Lubricate "G" rotary gates:
  - Grease sleeve bearings (LiEP2).
  - Check oil level in reducer (EP8).
- Rotary and retractable soot blowers:
  - Check operation cycle.
  - Check for steam leaks. Correct immediately.
  - Check valves. Tightly seated.
  - Check packing glands for proper tightness.
  - Clean off dirt and rust.
  - Check that mounting is secure.
  - Check cams and moving parts for lubrication.
- Rotary valves lubrication:
  - Oil drive gears and all other moving parts (Paradene 430).
- Retractable soot blowers:
  - Check chain for proper lubrication. Should rust form use special aerosol penetrating oil (CV1#39837, 139036).
  - Check gear box oil level (Super V10W-30).

Quarterly

- Grease shaft bearings (both sides), worm gear, and all other moving parts on butterfly valves.
- Check for smooth operation, especially sprocket of worm.
- Check operation and clean inking system of flow recorder, pressure recorder.

Semiannually

- Change gear motor oil on rotary gates "PN".
  - (Winter - EP5)
  - (Summer - EP8)

CONTINUED

TABLE 46. CONTINUED

Change gear motor oil on rotary gates "6" (EP8).
Change gearbox oil on retractable soot blowers (Super V10W-30).
Rotary soot blowers, check power pack gearbox oil (Super V10W-30).
Check rotary valve, blower and compressor motors.
Check bearing condition.
Check compressor pressure switch and low pressure alarms.
Check dust collecting sequencing system.
Check operation of soot blower control system.
Check condition of limit switches and lubricate.
Lubricate soot blower control relays (WD-40 or CR226).
Lubricate motor bearings (LiEP2).

Annually

Change oil in rotary soot blower power pack gear box.
Zero and calibrate:
    Export steam pressure indicating controller.
    Export steam pressure recorder.
    Export steam transmitter.
    Export steam back pressure indicating controller.
    Pressure valve.
Zero, calibrate, and check operation:
    Level transmitter.
    Level indicating controller.
    Boiler feedwater flow transmitter.
    Square root converters.
    Flow indicating controller.
    Computing relay.
    Flow transmitter.
    Boiler high level alarm.
    Boiler low level alarm.
    Level indicators.
    Pressure indicator.
    Economizer temperature indicators.
    Flow recorder.
    Boiler feedwater valve.
    Gas inlet pressure gauge.
    Gas exit pressure gauge.
Clean level electrode chamber.

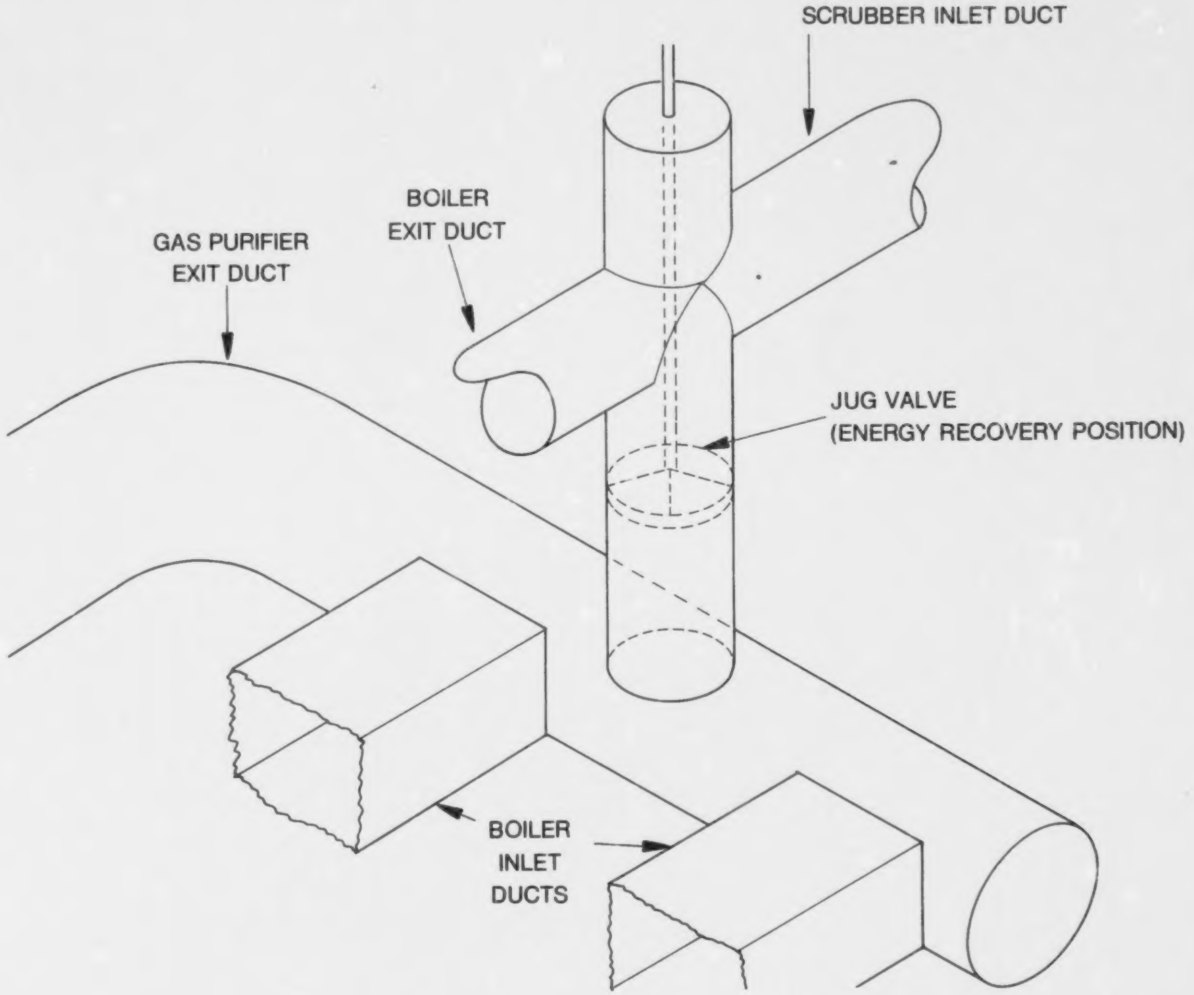

SCRUBBER INLET DUCT
BOILER EXIT DUCT
GAS PURIFIER EXIT DUCT
JUG VALVE (ENERGY RECOVERY POSITION)
BOILER INLET DUCTS

Figure 77. Schematic of the jug valve.

Within the vertical cylinder is a valve shaft with a disk (Figure 78) that is moved up or down to control the gas flow as follows: When the disk is lowered below the area connecting the boiler outlet duct to the scrubber inlet duct, all the gas passes into the boiler inlet ducts; when the disk is raised above this area, all the gas flows into the scrubber inlet duct because of the greater negative pressure there; and when the disk is positioned within the area connecting the boiler outlet duct to the scrubber inlet duct, the gas flows to both the boiler inlet ducts and the scrubber inlet duct. The relative amounts of gas to the boilers and the scrubber depends on the disk positioning in this area.

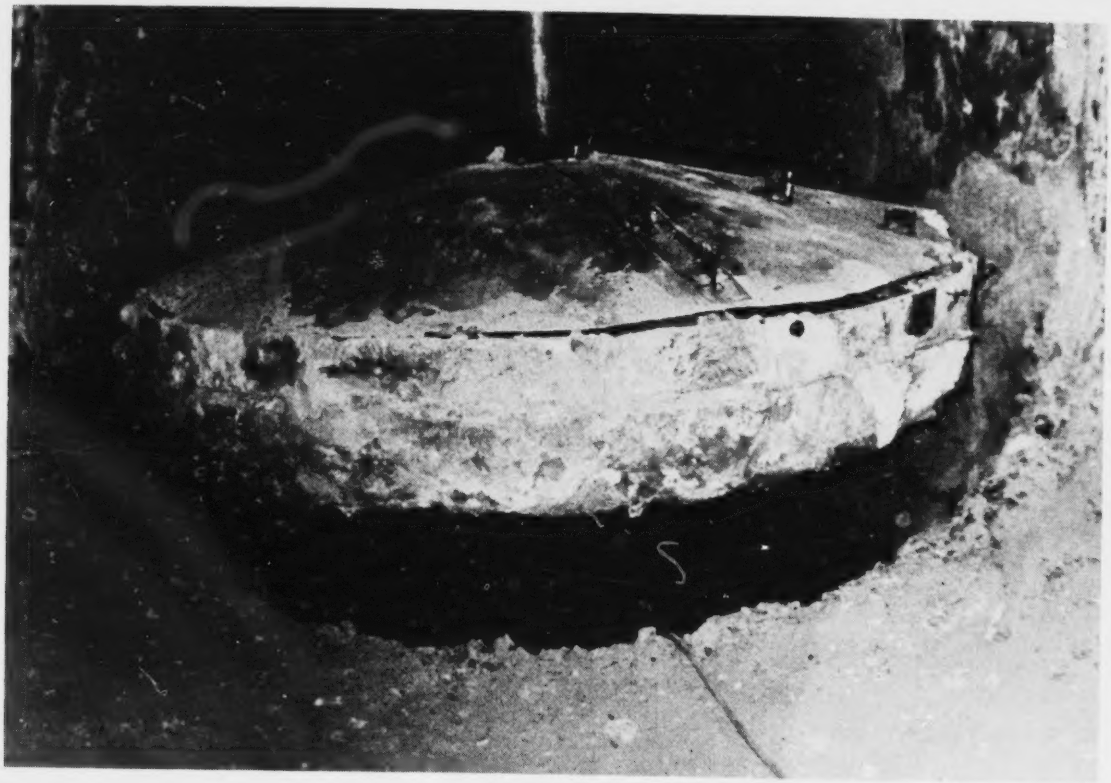


Figure 78. Jug valve.

Extending axially from the gas purifier, the gas purifier outlet is a circular duct with a 3.5-m (11-ft 6-in.) diameter. The duct is made of steel and lined with high temperature alumina brick which is 23-cm (9-in.) thick.

Each of the boiler gas inlets is a rectangular duct, 2.8-m (9-ft 5-in.) wide by 1.2-m (2-ft 10-in.) high, constructed of carbon steel and lined with castable refractory. To isolate a boiler for auxiliary repairs or emergency shutdown, each inlet duct has a swing gate which is a winch-operated block valve. The valved part of the gate with the winch above it forms a section of the inlet roof.

Each of the economizer exhaust gas outlets is also a rectangular duct. With inside dimensions of 1.3 m (4 ft 6 in.) high by 5.5 m (17 ft 6 in.) wide, the duct is made of steel with a gunnite refractory which is 1-cm (1/2-in.) thick. The two outlet ducts connect to a common horizontal header running perpendicular to the ducts. The header is a circular steel duct with no refractory lining and has a 2.4-m (8-ft) diameter. In the middle of the header is the exhaust gas outlet duct. Within the header and between the header outlet and each of the economizer outlet ducts is a butterfly valve. Adjusted by manually operated chains, the two butterfly valves provide the means for controlling the gas flow through the parallel boiler-economizer assemblies thereby maintaining equal steam pressures in the two boilers.

The header [illegible]t duct, also referred to as the boiler outlet duct as mentioned above, extends horizontally to flow through the vertical cylinder portion of the jug valve into the gas scrubber inlet duct. The last 4 m (12 ft) of the boiler outlet duct up to the jug valve is lined with gunnite refractory which is 10 cm (4 in.) thick.

The jug valve (Figure 78) is a globe valve with a sectioned refractory disk which moves up and down the cylindrical shaft of the valve. With a 2.4-m (8-ft) diameter and a 2.7-m (9-ft) stroke, the disk is raised and lowered by a variable-speed, DC drive at speeds between 0.5 and 16.8 mpm. While the speed can only be adjusted in the field, the valve may be operated either at the field control station or from the control room. The shaft and top of the valve are cooled by airflow induced through two inlet slots in the shaft.

Operating Experience

After the original castable refractory in the gas purifier outlet duct had failed, it was replaced with the alumina brick refractory mentioned above. Then after brick on the top edge of the boiler inlet ducts continued to fall out, the top edge of the inlet was changed from its rectangular shape to an arch which eliminated the brick fallout.

Since the gases flowing through the gas purifier outlet duct and the boiler inlet ducts contain large amounts of fly ash, and since the ducts are horizontal, considerable amounts of ash accumulate on the duct floors and must be manually removed periodically (Figure 79. After a 3-month operation,

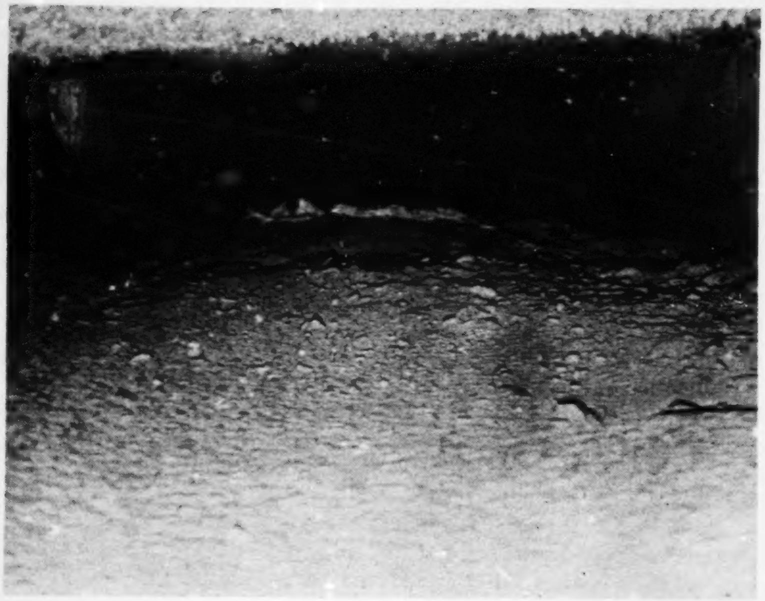


Figure 79. Fly ash build-up in the boiler inlet duct.

the ash accumulates to depths up to 30 cm (1 ft). Because of the limited access and the confined working area, the ash removal may require three men for 2 days.

The boiler inlet ducts originally had refractory-lined steel guillotine-type gates. After the heat had badly deformed these gates and slag and fly ash had accumulated in the slots to make the gate operation difficult and inefficient, the original gates were replaced with the current swing gates. However, the new gates occasionally jammed, and slag and fly ash accumulations on the gates so prevented their proper sealing that air would leak into the boilers. Moreover, while a closed swing gate would stop the gas flow sufficiently to prevent steam production in a boiler, the heat within the boiler shell would still be prohibitive for performing repairs in the boiler area.

After the quench air dampers were retrofitted in the gas purifier exit duct to cool the boiler inlet gases below the ash fluid temperature and thereby prevent the boiler tube slagging, thermocouples were installed in the boiler inlet ducts, and temperature readouts for them were added to the monitoring instruments in the control room. Consequently, the control room operators could then efficiently adjust the dampers to keep the boiler inlet temperatures below the ash fluid temperature.

A door was cut into the economizer outlet header duct to gain access to the butterfly valves. Whenever the valves jammed, they had to be cleared since there is no other means for adjusting the gas flow distribution such that the boilers would have equal pressure.

After the gas purifier gases flowing directly to the gas scrubber inlet duct had excessively heated the boiler outlet duct near the jug valve, the last 4 m (12 ft) of the duct up to the valve was lined with the gunnite refractory as mentioned above.

After the original jug valve refractory, a single piece of refractory, continued to fall out in pieces and had to be patched, it was replaced with castable segmented refractory to make repairs faster. In addition, gas leaked through the valve when its disk was lowered below the area for the scrubber inlet duct because slag and fly ash buildup on the valve and its seat prevented the complete valve closure.

Because of the continuing refractory failure in the jug valve, and particularly because of the gas leakage through the valve with its disk in the lowered position, the disk was sealed. Consequently, all the gas purifier exit gas flows only to the boiler inlet ducts.

Maintenance

Except for the system modifications and the emergency maintenance discussed above, the boiler inlet ducts and the jug valve have required only the preventive maintenance listed in Table 47.

TABLE 47. JUG VALVE PREVENTIVE MAINTENANCE

Monthly

Check for smooth operation, unusual noises, and heat in the reducer.
Check gear motor reducer oil level (EP8).

Semiannually

Change reducer oil (EP8).
Grease motor (LiEP2).
Check motor.
Check control circuit and position of indicator system.
Check operation of load cell shutdown system.
Check motor voltage control system.
Check position of all limit switches.

Annually

Megger motor.

Blowdown System

Located between the water treatment building and the boiler-economizer assembly near the economizer end, the boiler blowdown system consists basically of a separator and a surge tank. After the blowdown water enters the separator, the steam is vented to the atmosphere and the water flows to the surge tank for its discharge to the sewer.

Description

The blowdown for each boiler consists of two separate water removals: one for the steam drum where some of the water is constantly removed for the twofold purpose of keeping the dissolved solids concentration at a level between 1,400 and 1,800 mg per liter and of removing any floating scum; and the second from each of the two mud drums where water is removed once per shift, every 8 hours, to maintain a low-level concentration of suspended solids in the mud drums.

In each boiler, there is a blowdown line at each end of each of the two mud drums and one blowdown line for the steam drum. About 10 percent of the water entering the steam drum is constantly removed by skimming water from the water surface in this drum. As stated above, some of the water in each of the mud drums is blown down in each shift.

The water in each blowdown line flows under boiler pressure through insulated pipes to the common separator which is mounted above the surge tank (Figure 80). Upon entering the separator, the blowdown water is flash-cooled from 2,280 kPa (330 psig) to atmospheric pressure. The steam produced in the separator is vented to the atmosphere through a steam muffler mounted above the separator and the remaining water flows to the surge tank. Supplied by Wilson Engineering Corporation, the blowdown separator is a Model 24-V3FX centrifugal separator and its steam muffler is a Model 20-FM-10 unit.

While the surge tank continuously discharges water to the sewer, the water entering the tank has a short detention time. The surge tank is a vertically arranged cylindrical steel tank with a total volume of 26,500 liters (7,000 gallons), a retained water volume of 4,400 liters (1,150 gallons) before water overflows to the sewer, and a working water volume of 21,000 liters (5,550 gallons) before the water overflows to the ground. City water can be fed into the sewer discharge line to cool the blowdown water sufficiently to prevent thermal shock to the sewer tile.

For each boiler, a water-cooled sample line is installed on the steam drum blowdown line to collect samples for boiler water analysis. The sample line is enclosed in a heat exchanger shell with city water as the cooling fluid flowing through the shell.

Operating Experience

Water hammer occurs when the mud drums are blown. During the winter, the steam spraying from the separator has often condensed into water droplets

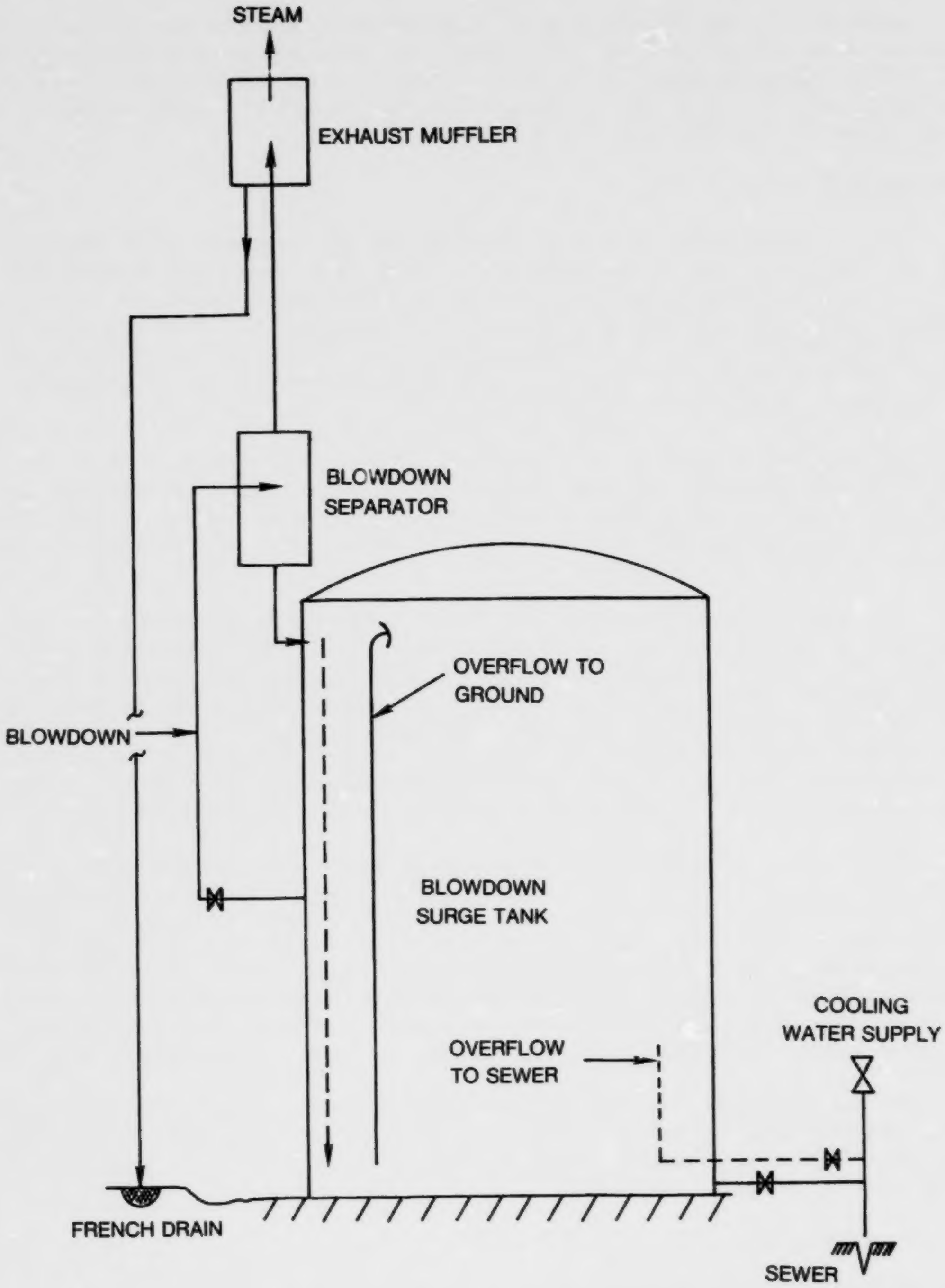

STEAM
EXHAUST MUFFLER
BLOWDOWN
SEPARATOR
OVERFLOW TO
GROUND
BLOWDOWN
BLOWDOWN
SURGE TANK
COOLING
WATER SUPPLY
OVERFLOW
TO SEWER
FRENCH DRAIN
SEWER

Figure 80. Blowdown surge tank and separator.

which have frozen on the ground to make nearby walkways and steps hazardous; also some valves have frozen.

Platforms had to be added beside the boiler shells to permit ready access to the blowdown valves. Although these valves are at the base of the boiler shells, they are still 2 to 3 m (7 to 10 ft) above the ground level.

Fly Ash Collection System

As previously discussed, the fly ash accumulating on the banks of the heat exchanger tubes in the boilers and economizers is periodically removed by the soot blowers to fall into the fly ash hoppers below the tube banks. The function of the fly ash collection system is to gather the fly ash emitted from the hoppers and to discharge the cumulative ash into slag trucks for landfill disposal.

Description

In each of the two boiler-economizer assemblies, there are six fly ash hoppers--four in the boiler shell and two in the economizer shell. All six are aligned along the assembly centerline. During the initial operation, a continuous fly ash collection pipe formed a horseshoe pattern to connect in series the outlets of the six hoppers of one boiler-economizer assembly and then the outlets of the six hoppers of the other assembly. At one end of the horseshoe line, a blower was installed to pneumatically force through the line the ash from all 12 fly ash hoppers; and at the other end, a dust collector subsystem was installed to gather and discharge the cumulative ash for landfill disposal.

On the bottom of each of the 12 fly ash hoppers is a rotary valve which maintains an air seal while allowing the discharge of the fly ash. Each of these valves is a 20-cm (8-in.) diameter Ducon star valve which has a cast iron rotor and housing. Driven by a 3/4-hp rotor, the valve has a capacity of 225 liters per hour (8 ft ^{3}/hr.) The ash collection is accomplished via a pneumatic pipe which begins at the blower and ends at the dust collector subsystem.

The fly ash blower is a Chicago Model 2T-15-20 centrifugal turbo-pressure blower with an inlet filter and an outlet control damper. Direct-driven at 3,500 rpm by a 20-hp motor, the blower has a capacity of 34 m^3 per minute (1,200 cfm) at a discharge pressure of 71 cm (28 in.) of water.

Upon receiving the cumulative fly ash, the dust collector separates the fly ash from the air stream for the air venting to atmosphere and the ash discharge into slag trucks for landfill disposal. The dust collector has a design air flow rate of 34 m^3 per minute (1,200 cfm) and a design solids flow rate of 363 kg per hour (800 lb per hour).

The dust collector subsystem consists of a container to receive the cumulative ash, tubular bags to filter the air into the atmosphere, a hopper to receive the falling ash, a vibrator attached to the hopper to accelerate the ash discharge, a rotary valve on the bottom of the hopper to function as the fly ash hoppers in the boilers and economizers, and an air compressor to generate pulsed air for the tubular bag blowback. The total filter area of the tubular bags is 23 m^3 (250 ft^2). Equipped with an automatic start-up control, the air compressor is a single-stage, single-acting unit with a V-belt drive. The air compressor has a capacity of 0.2 m^3 per minute (7 cfm) and is set to maintain the air receiver at a pressure of 587 to 621 kPa (85 to 90 psig). The entire dust collector subsystem was supplied by Flex Kleen.

Operating Experience

During the early operation of the Landgard plant, the fly ash collection system operated sporadically because of ash plugging throughout the system. Some of the plugging was due to the jamming of the rotary valves. These jammings were successfully eliminated by trimming the valves.

Some potential causes of the plugging were moisture and large pieces of fused ash particles entering the collection pipe. Moisture was considered as a potential plugging factor because of the condensation on the economizer tubes during start-up and other low-flow conditions. Such condensed moisture falling into the collection pipe is especially critical since the first and last of the series-connected hoppers are under the economizers. Therefore, when water forms on the economizer tubes and falls into the hoppers, the ash initially entering the collection pipe and the dust collector are moistened. The moistened fly ash forms large lumps or a slurry that cannot be moved pneumatically.

As the fly ash builds up on the heat exchanger tubes, the small ash particles coalesce into large masses which slough off in pieces as large as 8 cm (3 in.). Such pieces are too large to be moved by the pneumatic system and therefore remain stationary in the collection pipe to block the following ash. Large ash masses forming in the dust collector have bridged and plugged the dust collector hopper. The vibrator attached to this hopper has had little effect in dislodging such ash accumulations.

In any event, the major plugging factor has been the large mass of fly ash removed from the tube banks during the soot blowing periods. When the soot blowers are operating, each of the 12 fly ash hoppers had discharged up to 7 kg per minute (15 lb per minute) of ash. This ash flow rate is 10 times greater than the design ash flow rate.

To increase the pneumatic force, the original blower motor was replaced with a larger unit, the 20-hp motor mentioned above. However, the plugging throughout the fly ash collection system continued. Therefore, to prevent the buildup of fly ash in the boilers and economizers, the pneumatic collection pipe was removed and a 208-liter (55-gallon) drum was placed under each of the 12 fly ash hoppers as a temporary expedient. Although not as yet implemented, some other means of removing the ash should be developed since the drums can only be removed by manually manipulating them with a hand truck, a very laborious effort.

Maintenance

The rotary valves must be periodically lubricated with grease, although fly ash intermingling with the grease causes considerable wear. In addition, the rotary valve on the dust collector hopper has required minor repair. Some of the rotary valves were repaired or replaced because of damage sustained by construction materials, such as welding rods, that had been left in the boiler and economizer shells. The preventive maintenance schedule for the fly ash dust collector is shown in Table 48.

TABLE 48. FLY ASH TRANSFER SYSTEM PREVENTIVE MAINTENANCE SCHEDULE

Daily

Check compression oil level.
    (Winter - Super HDX 20)
    (Summer - HDX 30)
Drain air receiver, drop legs, etc.
Check for unusual noise, failure to compress, overheating, vibration, slippage, and check the belts.
Adjust pressure difference between 1-10 cm water gauge.

Monthly

Check rotary valve, motor, reducer, and chain.
Check and tighten all bolts on the air compressor, check all air connections, joints, and lines for leaks.
Check V-belt for misalignment and tightness (1 cm play midway between pulleys).
Check and tighten clamps on dust collector filter bags.
Check inlet air filter, check safety for sticking, and check belt tension.
Lubrication:
    Check oil in rotary valve gear motor
    (Winter - EP5)
    (Summer - EP8)

Quarterly

Check compressor valves.
Grease rotary valve bearings (EP2).
Oil chain (Paradene 430)

Semiannually

Check condition of bags.
Change compressor oil.
    (Winter - Super HDX 20)
    (Summer - HDX 30)
Grease motor (LiEP2)

RESIDUE SEPARATION MODULE

The residue separation module (Figure 81) was designed to separate the residue produced in the thermal processing module into three materials--magnetic metal, which was to be sold to a scrap dealer; glassy aggregate, which was to be used as an asphalt aggregate; and carbon char, which was to be landfilled unless a use for it could be proven.

The residue drag conveyor discharges the residue to the residue separation screen, and the portion of the residue passing through the screen falls into the residue separation unit. Then the char portion of the residue is separated by flotation. The char slurry is screened and dewatered by a roto screen, a thickener, and a vacuum belt filter. The char from the vacuum belt filter is conveyed and stacked on the ground by two char conveyors operating in series. Magnetic metals are then separated and discharged into trucks. The remaining glassy aggregate is conveyed and stacked on the ground by the glassy aggregate conveyors.

Evaluation of this module is difficult since it had a very short operating period. Performance of the module is very dependent on the quality of residue from the thermal processing area.

Residue Separation Screen

When the residue separation module is operated, kiln residue is discharged from the residue drag conveyor to the residue separation screen within the residue separation building. The screen allows residue particles smaller than 20 cm (8 in.) to pass through the screen falling into the residue separation tank. Residue particles greater than 20 cm (8 in.), such as slag, slide down the screen and are discharged into a truck or hopper outside the building for disposal.

If the residue separation module is bypassed and the residue is discharged from the residue drag conveyor through the bypass gate into trucks, cover plates are installed over the separation screen to restrict the residue from entering the residue separation tank. This procedure allows the unit to operate as a vibrating pan conveyor so that carryover residue is discharged to the residue truck (located under the bypass gate) for subsequent disposal.

Description

The residue separation screen is a vibrating screen conveyor supplied by the Materials Handling Division of the FMC Corporation. The conveyor is constructed of carbon steel 1.3 cm (0.5 in.) thick with abrasion-resistant, replaceable steel liner plates 1 cm (3/8 in.) thick. The conveyor is belt driven by a 3 hp motor and has a design capacity of 2,500 kg/hr (5,500 lb/hr) at a density of 800 kg/m^3 (50 lb/ft^3). The conveyor, sloped at an angle of 17°, is 2.7-m (9-ft) long and 0.9-m (3-ft) wide.

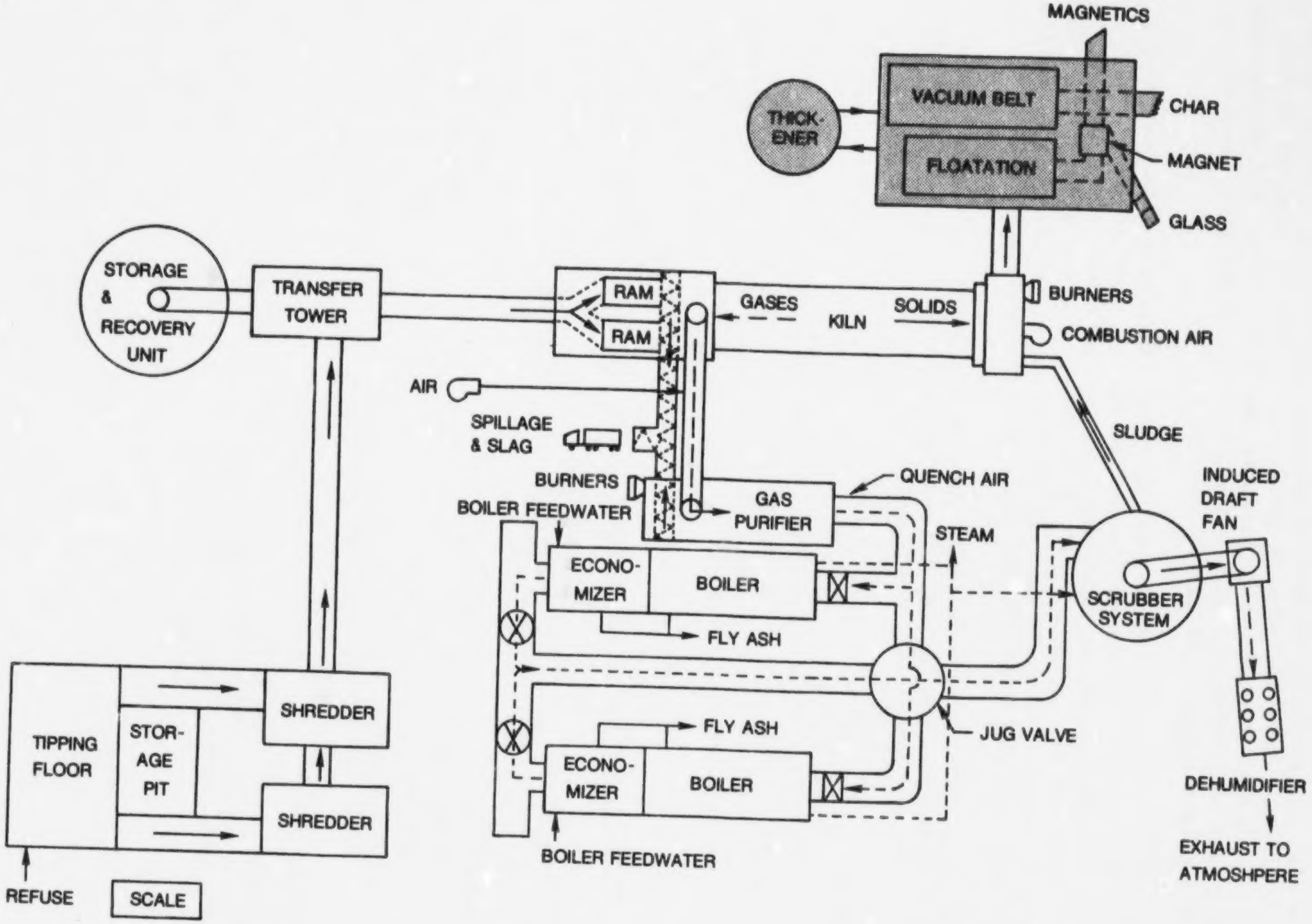

MAGNETICS
VACUUM BELT
CHAR
THICK-ENER
FLOATATION
MAGNET
GLASS
STORAGE & RECOVERY UNIT
TRANSFER TOWER
RAM
RAM
GASES
KILN
SOLIDS
BURNERS
COMBUSTION AIR
AIR
SPILLAGE & SLAG
SLUDGE
BURNERS
GAS PURIFIER
QUENCH AIR
BOILER FEEDWATER
INDUCED DRAFT FAN
STEAM
ECONO-MIZER
BOILER
SCRUBBER SYSTEM
FLY ASH
FLY ASH
JUG VALVE
TIPPING FLOOR
STOR-AGE PIT
SHREDDER
SHREDDER
ECONO-MIZER
BOILER
DEHUMIDIFIER
BOILER FEEDWATER
EXHAUST TO ATMOSHPERE
REFUSE
SCALE

Figure 81. Residue separation module (shaded area).

Operating Experience

The residue separation screen experienced many problems similar to the vibrating screen conveyor discussed earlier. Drive belts wore out quickly because the screen vibrated while the motor was stationary. The screen also jammed quickly with wire. In addition, accessibility was poor, making cleaning and maintenance difficult.

As mentioned earlier, the I-beam, on which the bypass gate pneumatic cylinders are mounted, blocks the large slag balls, causing a jam on the conveyor. Underprocessed residue, which has a high moisture content, does not move down the incline very well. A portion of the discharge chute from the residue conveyor to the residue separation screen was removed to allow a greater clearance for slag balls to slide down the conveyor.

The cover plate, which is installed over the screen when the residue separation module is not in use, allowed residue to leak through and cause problems with the residue flotation unit.

Maintenance

Maintenance has required placing the pulleys back on the sheaves, replacing the pulleys, and aligning the sheaves. Some bolts that have vibrated loose or sheared were replaced. The preventive maintenance schedule for this unit is shown in Table 49.

TABLE 49. VIBRATING SCREEN CONVEYORS

Weekly

Lubricate bearings lightly (LiEP2).

Quarterly

Check V-belts for:
- Tension.
- Broken bolts; replace if necessary.
- Rubber mounts location and wear; replace if damaged.

Semiannually

Grease motors (LiEP2).
Check motors, alarms, and interlocks.
Grease motor bearings (LiEP2).

Annually

Megger motor.

Residue Flotation Unit

Residue that has passed through the residue separation screen falls into the water-filled tank of the residue flotation unit which is inside the residue separation building. The residue is then mixed with the water and agitated by air from an air compressor. This process causes the lower density, carbon-rich char to float and flow over a weir through an open flume to the roto screen. A washed, heavy fraction containing metals and glass sinks and is removed from the unit by a drag conveyor that transfers this material to the sinks discharge conveyor.

Description

Supplied by the Jeffrey Manufacturing Co., the residue flotation unit includes a separation tank, an air compressor, and a drag conveyor. The separation tank is 1.6 m (5 ft 3 in.) high, 1.2 m (4 ft) wide, and 6.7 m (22 ft) long. Water depth in the tank is maintained at 1.5 m (4 ft 10 in.) for a water volume of 12,000 liters (3,200 gallons) and 12.7 cm (5 in.) of freeboard. Water (5,675 lpm or 1,500 gpm) and air (125 kg/hr or 276 lb/hr) at a combined pressure of approximately 165 kPa (24 psig) enter the tank through nine 3-cm (1 3/16-in.) nozzles on the side of the tank near the bottom.

The overflow weirs are located at the top of the tank on the sides. The air compressor is an air-cooled, reciprocating, belt-driven model mounted on an air receiver. The compressor has a capacity of 1.7 m^3/min (60 ft^3/min) and is equipped with a water-cooled moisture separator and automatic drain.

The drag conveyor consists of two single strands of Rex "H" mill chain with a drag flights that are 0.9 m (36 in.) long, 21.6 cm (8.5 in.) high, and spaced 30 cm (12 in.) apart throughout the chain. The conveyor travels at a speed of 7.8 m/min (25.5 ft/min) and is powered by a 2-hp motor. The drag conveyor will not operate unless the sinks discharge conveyor is operating; and if the drag conveyor does not operate, the residue bypass gate will open.

Operating Experience

Because of the limited operation of the residue separation module, little operating experience has been obtained for this unit. As mentioned earlier, a floater problem already exists in the residue quench tank. Since the floaters must be removed in any event, all the char should be removed from that tank with flotation equipment and overflow weirs, as with the prototype. Installation of such equipment in the residue quench tank would entirely eliminate the need for a residue flotation unit.

The overflow weirs and the flume to the thickener were enlarged to allow a greater char slurry flow, and doors were cut in the tank to permit easier access for cleaning.

One unusual aspect of the drag conveyor is that it pushes instead of pulls. A problem is caused by the drag line which is made of chain that works better in tension than in compression. Monsanto recalculated the drag conveyor loads and determined that the motor was undersized and that the conveyor was not strong enough. The unit was never modified, however, because the residue separation module had a low repair priority.

When the residue separation module is not operated, some residue falls through the gaps in the residue separation screen cover plates into the residue flotation unit. This buildup continued until it was too high to be removed by the drag conveyor. To keep the conveyor clear, the unit was cleaned and run for a short period each shift. This procedure worked until the water in the tank froze. After it was cleaned out again, the water level was dropped and the conveyor was run continuously.

The residue flotation unit did not separate very well. The flow to the thickener often included glass, aluminum, underprocessed paper, and rags. The flow to the sinks discharge conveyor often contained large amounts of char. Since the water and air entered the tank through a common nozzle, plugging of these nozzles became a problem.

Maintenance

Because the conveyor is underdesigned, the most common maintenance procedure for this unit has been to replace sheared pins. Other maintenance resulting from underdesign of the conveyor includes replacing flights, cleaning the tank, returning the chain to the sprocket, and tightening the chain.

The nozzles were cleaned twice and reconditioned once. A leak that required welding developed in the open flume, and the drag conveyor zero speed switch was rewired. The preventive maintenance schedules for the unit and the separation air compressor are shown in Tables 50 and 51 respectively.

Roto Screen System

The roto screen system is installed inside the residue separation building and consists of a roto screen and an oversized floats conveyor. The roto screen: (1) removes residue particles larger than 0.6 cm (0.25 in.) from the carbon-char-rich overflow slurry flowing to the thickener, and (2) discharges them on the oversize floats conveyor that carries these particles to a bin outside the building. The char slurry that passes through the screen goes to the thickener adjacent to the residue separation building. Removal of these larger particles minimizes pluggage of the thickener pipes and pumps.

Description

The roto screen is a variable speed, horizontal drum filter constructed of stainless steel. The screen has a field control station and a high-liquid-level alarm. Also the screen is interlocked so that it will not operate if the oversize floats conveyor is not running; and if the screen is not running, the residue bypass gate will open. The oversize floats conveyor

TABLE 50. RESIDUE FLOTATION UNIT

Monthly

Check for loose bolts, damaged flights or brackets, unusual wear and noise.
Check tension on drag chain.
Check reducer for unusual noise or heat, and check oil level (Paradene 475).
Check heat shaft alignment.
Top up lubricant in drive chain (Paradene 430).
Grease valve stems, pillow block bearings, and head shaft bearings (LiEP2).

Shutdown

Drain and clean tanks.
Inspect tanks and wear plates for wear or damage.
Check drag guides for damage.
Check nozzles for pluggage, damage, and erosion.

Semiannually

Change reducer oil (Paradene 475).
Check motor, alarms, and interlocks.
Check operation of zero speed switch and lubricate (20 W motor oil).
Grease motor bearings (LiEP2).

Annually

Megger motor.

TABLE 51. SEPARATION AIR COMPRESSOR

Daily

Drain any condensate from receiver and traps.
Check for any unusual noise or vibration.
Check oil level in compressor.
    (Winter - Super HD X 20)
    (Summer - Super HD X 30)

Weekly

Clean air filter in solvent and dry it.
Clean all external parts of compressor and driver.
Manually test safety valve for sticking.

Monthly

Inspect entire air system for leaks.
Inspect oil for contamination and change if necessary.
Check bolt tension and wear.

Quarterly

Inspect valve assemblies.
Check oil in compressor.
    (Winter - Super HD X 20)
    (Summer - Super HD X 30)

Semiannually

Grease motor (LiEP2).
Check motor and alarm.

is a flat, sliding rubber belt conveyor 30 cm (12 in.) wide and 7.6 m (25 ft) long. A 3/4-hp motor drives the conveyor, which is equipped with a field control station only.

Operating Experience

The roto screen was added as a modification and has worked well in solving many of the thickener's problems.

The motor for the oversize conveyor burned out because it was located outside the residue separation building and was not weatherproof. The conveyor ends very close to the building, making it difficult to place a bin under the discharge. Since the belt is the sliding bed type, material builds up on its underside, causing poor tracking and an overload condition.

Maintenance

No maintenance information is available for the roto screen. The oversize conveyor has required installation of a new motor repair to the bearings, and lacing of the belt. The preventive maintenance schedule for the roto screen is shown in Table 52.

TABLE 52. ROTO SCREEN PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check screen, wiper, side plates, etc. for damage.
Grease bearings and vari-speed (LiEP2).
Check oil in vari-speed reducer.

Semiannually

Change oil in vari-speed reducer (EP8).
Check motor.

Annually

Megger motor.

Thickener

The carbon-char-rich overflow slurry from the residue separation unit passes through the roto screen and flows to the thickener in an open flume. The slurry solids settle within the thickener, are collected at the bottom, and are pumped as a thickened slurry to the vacuum belt filter by the thickener underflow pump. The clarified water flows over the wier in the thickener to the thickener overflow sump and is recycled to the residue separation unit by the thickener pressure pump.

Description

The thickener is a 12.2-m (40-ft) diameter, carbon steel, open-top tank with a concrete bottom. The tank is adjacent to the residue separation building above the ground and has a peripheral water depth of 3.4 m (11 ft). The bottom is sloped toward the center 12.5 percent to allow a center water depth of 4.1 m (13.5 ft). The thickener is equipped with center-pier-supported, center-driven mechanisms for scum collecting and sludge raking. The unit was designed to receive 6,200 lpm (1,640 gpm) of water containing 0.9 percent solids (carbon, glass, ash, and nonferrous metals). The design overflow was to have a solids concentration of 100 mg/l and a flow of 5,750 lpm (1,520 gpm). The design underflow from the thickener was to have a solids concentration of 10 percent and a flow of 450 lpm (120 gpm). A flocculant concentration of 2.0 mg/l was to be maintained in the thickener by the addition from the flocculant system (described in the section on the scrubber solids separation system). If the rake mechanism halts, both a local horn alarm and a remote alarm in the control room will sound.

The underflow pump is a horizontal, centrifugal solids pump with a rated capacity of 750 lpm (200 gpm) at a total dynamic heat of 12.8 m (42 ft). The pump has an open vane impeller and is belt-driven by a 5-hp motor.

The thickener pressure pump is a Worthington Model 8-LR-13-B, horizontal, centrifugal, split-case pump. Driven by a 50-hp electric motor, the pump has a capacity of 6,960 lpm (1,840 gpm) at a total dynamic heat of 15.2 m (50 ft).

Operating Experience

Although little operating experience has been obtained for the thickener, many problems have been observed. The tank was not equipped with a drain so when the underflow pump suction pipe clogged there was no easy way to drain the tank. Neither was there an easy access to clear the clogged pipe until numerous cleanouts were installed. The underflow pump suction pipe has clogged more than once during the short operating period, possibly because of the glass in the char, or a pipe too small to handle the flow. The pipe was clogged with cans before installation of the roto screen and the screen on the end of the plume. Installation of a flush line to blow back this line could possibly help clear the pipe. To help prevent plugging, a diaphragm valve was installed on the underflow pump discharge, and a recycling line was installed from the discharge to the inlet plume to keep the underflow moving in the pipes. The motor for the underflow pump was elevated above the sump after the latter filled and the motor burned out.

When the underflow pipe clogs, other problems occur. If the thickened slurry is not removed, it continues to thicken until it cannot be pumped. At this point, it also gets too thick for the rake mechanism to move, causing damage to it.

The rake mechanism was also modified to allow maximum inlet flume clearance by removing projections. The scum collector plate was also raised to allow the whole length of the plate to break the water surface. Freezing occurs in the winter when the thickener is not in use. During these periods, the system should be drained.

Maintenance

During the limited operating period of the residue separation module, the thickener and the pressure pump have only required the preventive maintenance detailed in Tables 53 and 54. The thickener underflow pump has required replacement of gaskets and bearings, tightening of flanges, rewiring of the motor because it rotated in the wrong direction, and installation of a cleanout line. A new submersible pump was installed to replace the old pump. The preventive maintenance schedule for the underflow pump is shown in Table 55.

Vacuum Belt Filter System

The thickened carbon-char-rich slurry is pumped to the vacuum belt filter by the thickener underflow pump. The thickened slurry is then dewatered to form a cake, which is discharged to the char transfer conveyor. The vacuum air and filtrate water flow to the vacuum receiver, where the water and air separate. The water falls to the bottom of the receiver and is pumped by the filtrate pump to the wash sump pump, which in turn pumps the filtrate to the open flume that flows to the thickener. The air in the vacuum receiver is pumped by a vacuum pump through a snubber to decrease the noise level and further separate the liquid/air mixture before discharging to the atmosphere. City water is used to continuously clean the return run of the belt. This wastewater flows to the separation sump pump, which pumps it to the open flume to the thickener.

Description

The vacuum belt filter is a top-loading, horizontal unit with 7.7 m^2 (83 ft^2) of effective surface area. The one-piece molded belt is under continuous vacuum. The unit is equipped with an open-top, overflow-type feedbox with adjustable V-notch weirs to distribute the thickened slurry uniformly across the full width of the belt. The unit is equipped with vacuum manifold assemblies connected by flexible connectors to vacuum pans. Also included is a continuous wash system with wash headers on the return run, spray nozzles, and a waste collection drip pan extending the full length of the belt filter cloth to collect the belt wash and possible spills. The head pulley is driven by a variable speed, 5-hp motor with chain and sprocket drive to deliver a belt speed of 1.5 to 6.0 mpm (5 to 20 fpm). The unit is

TABLE 53. THICKENER PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check power chain drive for unusual noise, vibration, or heat.
Check reducers.
Check lubrication:
    Winsmith.
    (Winter - EP5)
    (Summer - EP8)
    (LiEP2)
    Worm shaft and shaft bearings (LiEP2).
    Worm, gear, and ring drive reservoirs.
    (Winter - EP5)
    (Summer - EP8)

Semiannually

Drain tank, clean and hose down wall and floor.
Check and tighten all bolts.
Check truss arms and note whether they are sweeping in the same plane.
Adjust tie angles or adjustable brace to each truss aim for most effective cleaning.
Replace any broken or badly bent squeegees.
Lubricate the chain drive (Paradene 430).
Change oil in Winsmith.
    (Winter - EP5)
    (Summer - EP8)
    (8MCTW)
Change oil in worm, gear, and ring drive reservoirs.
    (Winter - EP5)
    (Summer - EP8)
Lubricate motor (LiEP2).
Check motors and alarms.

Annually

Check and dismantle roller chain coupling.
Megger motor.

TABLE 54. PRESSURE PUMP PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check bearings, couplings, and packing.
Lubricate all valves (LiEP2) and take-up of teflon stick.

Quarterly

Lubricate pump bearings (polyplex EP2).

Semiannually

Grease motor (LiEP2).
Check motor and alarm.

Annually

Megger motor.
Zero, calibrate, and check operation of discharge pressure indicator.

TABLE 55. UNDERFLOW PUMP PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check bearings, belts, packing, and motor bearings.
Lubricate all valves (LiEP2) and take-up on teflon stick.

Quarterly

Lubricate bearings (LiEP2).

Semiannually

Grease motor (LiEP2).
Check motor and alarm.

Annually

Megger motor.
Zero, calibrate, and check operation of discharge pressure indicator.

designed to (1) dewater 38,800 kg/hr (85,500 lb/hr) of a 10 percent solids slurry, and (2) to produce 16,200 kg/hr (35,600 lb/hr) of 24 percent solids cake, 375 lpm (100 gpm) of filtrate, and 75 lpm (20 gpm) of belt wash water.

The vacuum receiver is a cylindrical, dished-head, vertical tank 0.9 m (3 ft) in diameter and 1.8 m (6 ft) high. The tank is equipped with a vacuum gauge and a high-level probe.

The filtrate pump, mounted on the vacuum receiver, is a horizontal, centrifugal pump rated at 100 gpm at a total dynamic heat of 20.7 m (68 ft) of water.

The wash sump pump is a vertical, centrifugal pump with a capacity of 950 lpm (350 gpm) at a total dynamic heat of 13.7 m (45 ft) of water. The pump is equipped with a vertical float switch and cover. In case of pump failure, the sump is equipped with an overflow line to the separation pump.

The vacuum pump is a horizontal, positive displacement, rotary lobe, water-sealed vacuum pump with a rated capacity of 56.6 CMM (2,000 CFM) at a negative gauge pressure of 51 cm (20 in.) of mercury. The pump is equipped with a vacuum relief valve in the inlet piping.

The snubber is a vertical, cylindrical steel tank 56 cm (22 in.) in diameter and 138 cm (72 in.) high. The water removed by the snubber is discharged to the separation sump.

The separation sump pump, supplied by Standard Power, is a vertical, centrifugal pump with a capacity of 190 lpm (50 gpm) at a total dynamic head of 9 m (30 ft) of water. The pump is equipped with a float switch control and a cover.

Operating Experience

Operating experience obtained during the short operating period has revealed that the vacuum belt filter operates acceptably after some minor debugging, but that the unit requires substantial operating manpower. Some of the debugging modifications included replacement of a straight discharge from a pipe onto the filter with the distributing feedbox. Another modification was the change from thickener overflow water to city water for use in filter washing after the spray nozzles continually plugged.

A grit-settling box was installed to allow the glassy grit washed from the filter to settle out before entering the separation sump and possibly damaging the pump. However, no equipment exists for removing the glassy grit from the settling box. The amount of glassy grit in the char is much greater than anticipated and could increase the wear of the system significantly.

Maintenance

Before the glassy grit settling box was installed, the grit damaged the separation sump pump to the extent that the seals and impeller were replaced. The filter cloth for the vacuum belt filter was replaced after it was damaged during the construction period, and it was mended a few times during the brief operating period. The other pieces of equipment required only preventive maintenance. The preventive maintenance schedules for the vacuum belt filter, the vacuum pump, and the filtrate pump are shown in Tables 56, 57, and 58.

Char Conveyors

Carbon char discharged from the vacuum belt filter falls onto the char transfer conveyor, which carries the char to the char stacker conveyor. The char stacker conveyor takes the char to a storage pile or directly into trucks for landfill disposal.

Description

Both of these conveyors are Barber-Green, rubber belt, trough conveyors. They are 61 cm (24 in.) wide, with rubber belt wipers at the head pulley and are driven by 3-hp electric motors. The two conveyors are interlocked so that the transfer conveyor will not operate unless the stacker conveyor is operating. Both units are equipped with local controls and remote controls in the control room.

The transfer conveyor is horizontal and operates at a speed of 30 mpm (110 fpm). The stacker conveyor is inclined at an angle of 18°, is 24 m

TABLE 56. VACUUM BELT FILTER PREVENTIVE MAINTENANCE SCHEDULE

Each shift

Lubricate cloth roll bearings and aligning roller heads (Pyroplex EP2).

Daily

Check filter cloth for biasing and wrinkling.
Align rollers.
Check for side leaks and adjust rubber side seals if necessary.
Check take up pulley springs by measuring lengths of spring guide showing in spring enclosure: 1 cm - not operating, flush - operating.
Grease cloth roll bearings and aligning roller heads (Pyroplex EP2).

Weekly

Inspect flexible connections for leaks and alignment.
Check belt alignment.
Lubrication:
  Drive chain (brush on EP5).
  Pulley bearings (EP2).
  Cloth take-up mechanism (EP2).
  Aligning tension rod assembly (EP2).
  Drainage belt alignment mechanism bearings (EP2).
  Drainage belt roll bearings (Pyroplex EP2).

Monthly

Examine the belt for wear or damage and for trapped abrasive material between it and the pulley or vacuum pan.
Check the cloth rolls for solids build up and free turning on bearings.
Check loose assemblies, connections, bolts, and piping.
Inspect the wash pipe for direction and pattern of spray.
Clean all nozzles.
Clean line strainers.
Check zerk fitting on top of reducer (EP2).
Check cyclodrive, vari-drive, and reducer oil level.
  (Winter - Paradene 430)
  (Summer - Paradene X1000)
Grease vari-drive reducer (LiEP2).

CONTINUED

TABLE 56. CONTINUED

Semiannually

Clean and inspect the extractor for general condition during shutdown. Wash out the wash troughs or drip pan feed box. Release tension on cloth and inspect. Change cyclodrive and vari-drive reducer oil.
(Winter - Paradene 430)
(Summer - Paradene X1000)
Check motor, bearings, and alarm.

Annually

Megger motor.

TABLE 57. VACUUM PUMP PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check pumps for hot spots and vibration.
Check V-belts for tension and wear.
Check inlet and discharge pressure, and temperature performance standards.
Check oil level (Paradene X1000).

Quarterly

Grease motor (LiEP2).

Semiannually

Check alarm and interlock.
Check high temperature cut-off switch.
Check high liquid level shutdown switch.

Annually

Megger motor.
Zero, calibrate, clean, and check operation of water flow indicator rotometer.

TABLE 58. FILTRATE PUMP PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check pump, belts, drive, and packing.
Fill oil reservoir to center of sight glass (Paradene 430).

Semiannually

Grease motor (LiEP2).
Check motor, alarm, and interlock.

Annually

Megger motor.

(80 ft.) long, and operates at a speed of 46 mpm (150 fpm). The discharge end of the stacker conveyor can be rotated in a small arc by manually pushing it on a track.

Operating Experience

Except for the belt wipers, the char conveyors have worked well. The belt wipers do not clean the belt adequately, and they wear out rapidly, allowing a constant buildup to develop beneath the conveyors. A chute to guide the char from the stacker conveyor to the truck would be helpful in preventing material spills and blowing char. A divertable chute would be helpful in preventing spills when channging trucks.

Maintenance

The char conveyors have required only the preventive maintenance detailed in Table 59 during their short operating period.

Magnetic Metal Separation System

The portion of the residue that sinks in the residue separation tank is removed by the drag conveyor in that unit and is discharged onto the sinks discharge conveyor. A magnetic metal separation conveyor suspended above the sinks discharge conveyor removes all magnetic metal and deposits it on the iron transfer conveyor. The iron transfer conveyor discharges the magnetic metals and discharges them into a truck for sale to a scrap metal dealer. The portion of the residue remaining after magnetic separation (glass, ash, char, and nonmagnetic metals) is discharged by the sinks discharge conveyor onto the aggregate screen.

TABLE 59. RUBBER BELT RESIDUE CONVEYOR PREVENTIVE MAINTENANCE SCHEDULE

Weekly

Check alignment and tension of belts, belt lacing, belt wear or damage, and belt wipers for wear and proper action against belt.
Check idlers for lubrication, wear, and buildup.
Check motor reducer, belts, and guards.
Check general buildup.
Note any vibration or noise.
Check gear reducer oil level (EP5).
Clean sight glasses where necessary.

Monthly

Lubricate gear reducer, shaft bearings, and belt wiper assembly (LiEP2).

Quarterly

Grease idler bearings, exterior bearings (LiEP2).
Change reducer oil (EP5).
Oil stocker drive chain.
    (Winter - Paradene 430)
    (Summer - Paradene 475)

Semiannually

Grease motors (LiEP2).
Check motors, alarms, and interlocks.
Inspect and lubricate pull cord switch.

Annually

Megger motors.

Description

The magnetic metal separation system is located within the residue separation building. The sinks discharge conveyor is a 106 cm (42 in.) wide, flat rubber-belt conveyor with 15 cm (6 in.) skirt boards. The conveyor, supplied by Barber-Green, operates at a speed of 15 mpm (50 fpm) and is driven by a 1-hp motor. The conveyor is equipped with field controls and remote controls within the control room. This conveyor is interlocked with the aggregate screen and will not operate unless the screen is operating.

The magnetic metal separation conveyor is a suspended rubber belt conveyor with an electromagnet in the head pulley. The conveyor is aligned perpendicular (Figure 82) to the sinks discharged conveyor and has a design capacity of 9 Mg/hr (10 tph). The conveyor, supplied by the Eriez Magnetics Co., is driven by a 5-hp motor and has an 8-kw electromagnet. The unit is equipped with field controls and a remote start/stop switch in the control room. The belt is 61 cm (24 in.) wide and is designed to operate with a 5 cm (2 in.) of burden.

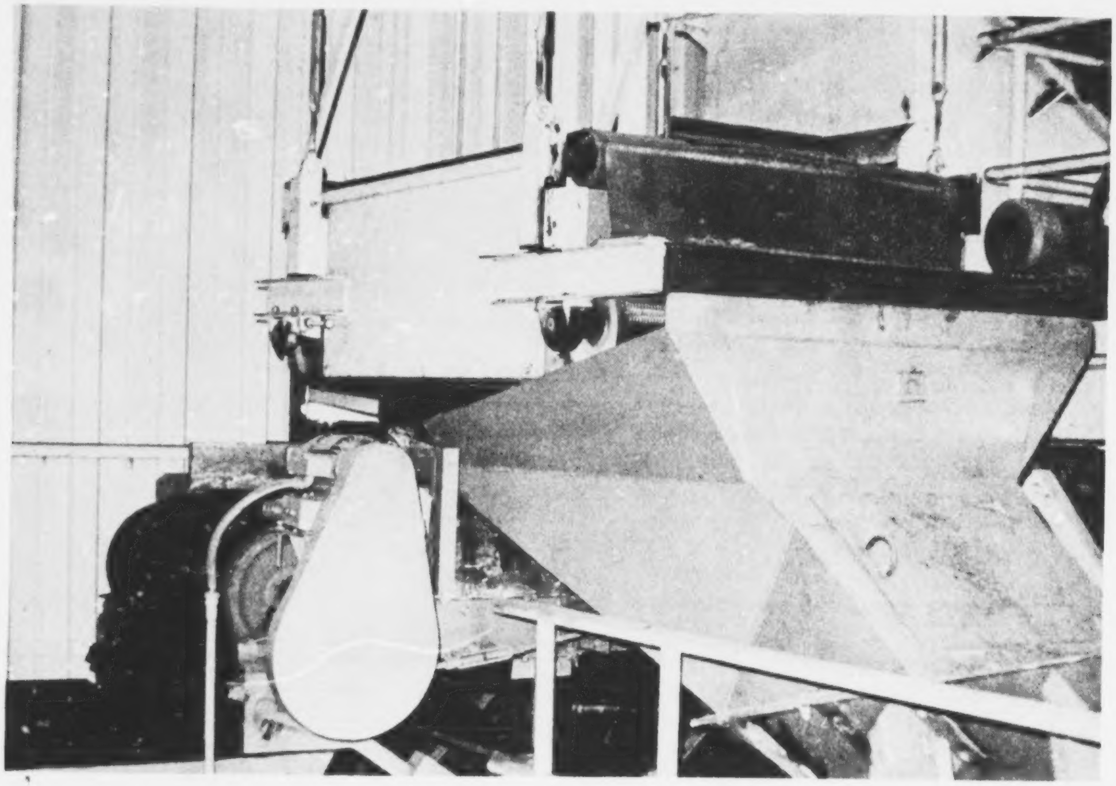


Figure 82. Magnetic metal separation conveyor.

The magnetic metal transfer conveyor is a 61-cm (24-in.) wide, troughed rubber belt conveyor. Supplied by Barber-Green, this conveyor is driven by a 3-hp motor and operates at 30 mpm (100 fpm). Also included with the unit are a field control station and a remote start/stop switch in the control room, two discharge chutes, and a local chain-operated flop gate to control the discharge flow to either chute.

Operating Experience

The sinks discharge conveyor has had a problem with spillage but has otherwise operated satisfactorily.

The magnetic metal separator produced a fairly clean product but had serious equipment problems. The original belt on the magnetic metal separator was plastic, and it was damaged by dry rot and cracking. The belt was replaced with a belt made of stainless-steel-reinforced rubber. Because of the pushers on the belt, belt wipers could not be installed. This situation allowed material to build up on the belt and cause a spillage problem. Originally, the belt moved very quickly throwing the metal. Belt speed of the magnetic metal spearator was reduced, and a plate was installed at the discharge to reduce the velocity of the separated magnetic metal.

As with the char conveyors, belt wipers were a problem with the magnetic metal transfer conveyor. An extra chute was added so that either of two trucks could be filled. This procedure reduced the total truck driver time and also prevented the spills that occurred during the truck change with one chute. The discharge chute clogged several times. The clogging was due wither to magnetic metal buildup within the chute when the trucks were not moved soon enough or to wire or spring wedging in the converging part of the chute.

Maintenance

In addition to the required preventive maintenance for the sink discharge and magnetic metal transfer conveyors shown in Table 59, the sinks discharge conveyor required frequent alignment.

The belt for the magnetic metal separator was replaced three times and spliced once. The shaft bearing for this conveyor was also replaced once. The preventive maintenance schedule for this conveyor is shown in Table 60.

Glassy Aggregate Conveyors

The portion of the residue remaining on the sinks discharge conveyor after the magnetic metals are removed is discharged onto the aggregate screen conveyor. The aggregate screen conveyor removes all residue particles larger than 1.2 cm (0.5 in.) and discharges them to a dump box outside the residue recovery building. The residue particles smaller than 1.2 cm (0.5 in.) pass through the screen onto the aggregate transfer conveyor. The aggregate transfer conveyor carries the glassy aggregate to the aggregate stacker conveyor, which discharges it to the glassy aggregate storage pile.

TABLE 60. MAGNETIC METAL SEPARATOR PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check oil level with magnet cold.
Check expansion tank pressure relief valve for freeness.
Check temperature (normal operating temperature is 60°C - 80°C above ambient); check further if not hot.
Check for proper belt tracking and adjust if necessary.
Check for leakage of oil.
Check motor and reducer for noise, vibration, or excessive heat.
Check V-belts for tension and wear.
Lubricate bearings (LiEP2).
Check reducer oil level (Paradene 475).

Semiannually

Check transformer oil in electromagnet; when cold.
Change reducer oil (Paradene 475).
Grease motor (LiEP2).
Check output voltage and amperage to magnet for all three phases.
Lubricate off/on switch for magnet.
Check motor and alarm.

Annually

Megger motor.

Description

The aggregate screen conveyor, supplied by the FMC Corporation, is a vibrating pan conveyor 2.6-m (8 ft 6 in.) long and 0.9-m (3 ft) wide at an angle of 17.5°. Originally, the conveyor had long rectangular openings 1.2-cm (0.5-in.) wide. The conveyor is belt driven by a 3-hp motor and has a field-mounted control station and a remote start/stop switch in the control room.

The aggregate transfer and stacker conveyors are both 60-cm (24-in.) wide, rubber belt, troughed conveyors supplied by Barber-Green. Both conveyors are equipped with a field-mounted control station and a remote start/stop switch in the control room.

The aggregate transfer conveyor is 54 m (177 ft) long and operates at a speed of 30 mpm (100 fpm). The conveyor is driven by a 3-hp motor and is interlocked to prevent operation unless the stacker conveyor is operating.

The aggregate stacker conveyor is 31 m (102 ft) long and is inclined at an angle of 17°. The conveyor is driven by a 3-hp motor and operates at a speed of 46 mpm (150 fpm). Another 3-hp motor is used to move the discharge end along an arc to make a larger storage pile.

Operating Experience

During the brief period that these conveyors were operated, very few operational or equipment problems developed. The rubber belt conveyors had the same problems as the other rubber belt conveyors, such as spillage and poor belt wiper performance and wear.

Because of the great reductions in cross section, the chute to the aggregate screen jammed on a few occasions. The screen had the same problem as the other vibrating pan conveyors in that the motor was on a stationary mount and the conveyor vibrated, damaging or throwing the belts.

Most of the nonmagnetic metals (especially brass and copper) are discharged as oversize particles from the aggregate screen conveyor.

Since the screen is too close to the ground to install a larger box, the screen openings were increased after large amounts of material were separated by the screen causing the frequent changing of the drop box. The aggregate screen conveyor, as with the other vibrating screens, was blinded by wire and required frequent cleaning.

Because the brakes for the stacker conveyor work only while the unit is on, the unit must be kept on to prevent it from being blown around by the wind. The stacker conveyor thus used power even when not in use.

Maintenance

As with the other vibrating conveyors, the belts for the aggregate screen conveyor were placed back on the sheaves after falling off. The preventive maintenance schedule for the vibrating conveyor was shown in Table 49.

The two rubber belt conveyors were each adjusted twice so they would track properly. The preventive maintenance schedules for these conveyors are shown in Table 59.

GENERAL PLANT MODULE

Certain pieces of equipment cannot be considered a portion of a one module, but rather a portion of the general plant. Such equipment usually performs a utility function.

The major pieces of equipment for the general plant module are as follows:

1. Atomizing steam boiler
2. Plant water system
3. Instrument air system
4. Dust collection system
5. Sump pumps
6. Wastewater lift station

Though most of this equipment caused some problems, the atomizing steam boiler and the dust collection system never performed adequately.

Atomizing Steam Boiler

The atomizing steam boiler is located outdoors, adjacent to the kiln fire hood. According to original design, the boiler was required to provide atomizing steam for the fuel oil burner system and steam to drive the turbine-driven, kiln-combustion air fan.

Description

The atomizing steam boiler is a small fire-tube boiler with a design steam capacity of 1,570 kg/hr (3,450 lb/hr) at a pressure of 1,380 kPa (200 psig). The boiler is fired using No. 2 fuel oil, and it is provided with its own feedwater system in the water treatment building.

Operating Experience

Immediately after the initial start-up, the frequent failures of the atomizing steam boiler caused serious problems. Because this unit supplied the atomization steam to the burners, the failure of the boiler caused all the burners to go out, shutting down the entire process. Many of the problems were electrical and weather-related because this unit is typically used indoors.

To improve boiler reliability, a standby or auxiliary feedwater pump was installed, and the drive for the integral combustion air fan was changed from a 5-hp turbine to a 7.5-hp electric motor. A low steam pressure alarm was also added to indicate when the boiler was malfunctioning.

When these modifications failed to increase the reliability of the unit, an auxiliary steam line was installed from the header of the waste heat boilers. This change was accomplished so that the atomizing steam boiler was required during heat up.

Several other problems were encountered in addition to boiler reliability. Most of the valves are above the boiler and out of reach; so, the operators used a portable ladder until a permanent ladder was installed. The blowdown line originally discharged above the ground in mid air. Because this situation could result in serious injury to plant personnel, the blowdown line was extended below ground in a French drain.

When the boiler continued to be a problem, the decision was made to use steam from the Baltimore Gas and Electric Co. for start-up, thus eliminating the need for the boiler. As mentioned in the burner section, the need for this boiler could be eliminated by using air-atomized burners.

Maintenance

In addition to the preventive maintenance shown in Table 61, the boiler required emergency maintenance frequently. Valves often had to be repaired or replaced. To repair leaks, gaskets were replaced, bolts were tightened, piping was replaced, and the packing at joints was tightened and replaced. The feedwater pump was rebuilt, and the motor coupling for the auxiliary pump was aligned. The fan motor bearings required replacement, and numerous gauges and sight glasses were installed.

TABLE 61. ATOMIZING STEAM BOILER PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check feedwater pump packing.
Grease feedwater pump bearings (LiEP2).

Quarterly

Check feedwater pump packing.
Grease feedwater pump bearings, blow down valve, air blower bearings on boiler (LiEP2).
Check coupling.

Semiannually

Grease motors (LiEP2).
Check feedwater pump and blower motors.
Check bearing condition and lubricate if necessary.
Check boiler feedwater reservoir level controller and feedwater valve.

Annually

Megger motors.

Plant Water System

The plant water system consisted of a potable city water supply and a recycled cooling water system. The city water is used for sanitary purposes, cooling water, make-up water, boiler feedwater, and fire prevention. A looped main line allows plant operation without interruption while major portions of the in-plant water lines are being repaired. The recycled cooling water system supplies cooling water to the kiln trunnions, kiln drive clutch, stack lid seal, gas analyzers, and ram coolers.

Description

Most of the city water supply piping is underground. From the water main underneath the street in front of the plant, a 20-cm (8-in.) pipe is used to convey the water into the plant. The flow of water into the plant is measured by a meter located just inside the plant fence. Beyond the meter, the piping branches into two distinct 20-cm (8-in.) pipes that connect again at the rear of the plant to form a loop. A block valve is located at the beginning of each line and at the junction of the two lines at the rear of the plant. A low pressure alarm is mounted on the 15-cm (6-in.) line to the water softeners. Backflow preventers are installed in the water supply lines to the process equipment.

The recycled cooling water system consists of a receiving basin kiln that receives heated cooling water from the users. A 5 hp Gould pump is used to pump this water to a Marley (75 ton) cooling tower. The cooled water is then pumped back to the users by a 10-hp Gould pump. All motors have local start/stop stations only. The portion of the system used to cool the gas analyzer probes is equipped with Worthington 1.5 1 and 1 hp cooling water booster pumps. A dual city-water backup system is provided for the equipment cooled by recycled water. The recycled cooling water line to the eddy current coupling of the kiln drive is equipped with a switch that will activate an alarm in the control room and stop the kiln drive motor in the event of low water pressure.

Operating Experience

The major problem with the city water supply has been one of reliability. The loss of city water or low water pressure has caused a few emergency shutdowns plus various other problems. Loss of city water has resulted from broken water mains outside the plant, repair to water mains outside the plant, and the repair of a fire hydrant pipe within the plant. The water supply system was connected to the smaller of the two water mains in the street in front of the plant instead of the larger, as originally designed. Based on a computer simulation by Monsanto, the smaller main could not supply the water demand of 7,570 lpm (2,000 gpm) while maintaining a pressure of 345 kPa (50 psig). Because of the insufficient water supply and pressure for a kiln, rams, stack lid, and gas analyzer probes, a water recycling system was added as a modification.

To prevent the loss of operating time when city water is lost, an elevated storage tower should be installed. Such a tower should also solve the problem of low water pressure.

More block valves are required within the water supply loop so that small areas can be repaired without disruption to more than half of the water system.

One of the major problems with the recycled cooling water system has been freezing. Freezing rarely occurs if the plant is operating, but it can be a significant problem if the plant is down during below freezing conditions. Since some lines, such as kiln trunnion coils, cannot be insulated and heat traced, the entire system should be drained during downtime.

Maintenance

The city water supply system required no maintenance except for the repair of a frozen fire hydrant that ruptured. The water recycling system on the other hand has required considerable repiping to repair freeze damage.

Instrument Air System

The instrument air system is used to provide dry, oil-free, compressed air to pneumatic controls and cylinders throughout the plant.

Description

The instrument air system consists of a Worthington 625-rpm, single-stage compressor capable of delivering 2.75 m^3min (97.3 ft^3/min) of compressed, oil-free air at a maximum pressure of 786 kPa (125 psig). A Kellogg-American, single-stage, single-acting compressor is installed as a spare capable of delivering 2.04 m^3/min (72 ft^3/min) of compressed, oil-free air at a pressure of 690 kPa (100 psig). The units share two common receivers--one in the water treatment building, and one by the rams. The receivers are cylindrical, vertical, steel pressure tanks.

The air-drying steam is composed of a primary unit consisting of a Deltech heatless dual chamber air dryer with prefilter and a spare unit installed in parallel, a Pall Trinity heat-reactivated, dual-chamber air drier.

Operating Experience

The present spare unit was originally installed as the primary unit with no spare. The compressor had insufficient capacity and was unreliable, so the present larger primary unit was installed.

The system has operated well except that the spare unit has failed to start when the pressure dropped below the set point on a few occasions. To avoid condensation in the standby compressor, a cooling water condensation trap was installed.

Also the purge valve for the regeneration of the air drier jammed frequently.

The receiver by the ram was not originally installed but was added as a modification when it was realized that the pneumatic lines to the stack lid had insufficient surge capacity.

Maintenance

In addition to preventive maintenance (Tables 62 and 63), the major maintenance requirement was to repair cooling water lines. Compressor rings were required, and the low pressure switch was replaced. To stop an oil leak, the inspection plate was tightened, and the compressor valves froze once.

Dust Collection System

The system collects dust-ladden air from the shredders, the storage and recovery unit, the transfer tower junction points, the ram feed hopper, and the shredded refuse conveyor transfer points. The large dust particles are removed by cyclonic action in the dust collectors and are discharged through the bottom to the shredded refuse stream. The air and the smaller dust particles are pneumatically conveyed through a length of steel duct to the dust collection fan, which creates the suction draft that induces the air flow throughout the system. The duct collection fan discharges the air and fine dust into the kiln crossover duct. The dust is then combusted in the gas purifier to eliminate dust and odors.

Description

All of the dust collectors were supplied by the Ducon Co. and are equipped with neoprene-stripped, cast iron, non-spark rotary valves. The dust collection fan is discussed in detail in the combustion air fan section.

One dust collector is located inside each shredder building, with collection points at the shredder feed conveyor discharge and the transfer point from the shredder discharge conveyor to the shredded refuse collection conveyor. The collector in one shredder building also collects at the transfer point from the shredder refuse collection conveyor to the shredded refuse elevating conveyor. Both dust collectors are designed for an air flow rate of 142 m^3/min (95,000 ft^3/min) at an inlet suction pressure of 10 cm (4 in.) of water. Both collectors discharge the large dust particles to the shredded refuse collection conveyor.

The dust collector located in the enclosed top of the storage and recovery unit has only one collection point. This point is where the shredder refuse transfer conveyor discharges to the stored material spreader. The collector is designed for an air flow of 28 m^3/min (1,000 ft^3/min) and an inlet suction pressure of 5 cm (2 in.) of water. The collector discharges the large dust particles to the storage and recovery unit.

TABLE 62. INSTRUMENT AIR COMPRESSOR PREVENTIVE MAINTENANCE SCHEDULE

Daily

Check oil pressure.
Drain condensate from receiver and traps.
Check for any unusual noise or vibration.
Check oil level.
    (Winter - Super HD X 20)
    (Summer - Super HD X 30)

Weekly

Clean air filter with solvent and dry it.
Clean all external parts of compressor and driver.
Manually test safety valve for sticking.

Monthly

Inspect entire air system for leaks.
Inspect oil for contamination and change if necessary. .
    (Winter - Super HD X 20)
    (Summer - Super HD X 30)
Check belt tension and wear.
Check oil filter screen.

Quarterly

Change oil.
    (Winter - Super HD X 20)
    (Summer - Super HD X 30)
Inspect valve assemblies, rings, and clearances.
Clean oil filter screen.
Disassemble; inspect and clean oil pressure relief valve.

Semiannually

Grease motor (LiEP2).

Annually

Clean and calibrate instrument air pressure alarm and switch.
Zero, calibrate, and check operation of discharge pressure indicator.

TABLE 63. INSTRUMENT AIR DRYER PREVENTIVE MAINTENANCE SCHEDULE

Weekly

Check operating condition:
  Line pressure.
  Line temperature.
  Inlet flow.
Inspect Aquadex Moisture Indicator (make sure bleed is open).
Check pressure difference across prefilter and afterfilter.
  Greater than 69 kPa (10 psig).
Check purge indicator for air flow.

Quarterly

Check outlet dew point (should be - 40°F).
Check prefilters, replace as required.
Check blowdown relief valves and the condition of the element.

Semiannually

Inspect and replace prefilters and afterfilter cartridges as required.
Change Alumina afterfilters.

Annually

Inspect desicant and replace if necessary.
Inspect and clean or replace seats on check valve.
Inspect and clean solenoid valves.
Change prefilters if not done during Quarterly or Semiannually inspection.

The transfer tower dust collector has collection points at (a) the discharge of the shredded refuse elevating conveyor, (b) the transfer point from the storage and recovery outfeed conveyor to the kiln feed conveyor, (c) the transfer point where the bypass chute deposits on the kiln feed conveyor, and (d) the tail end of the shredded refuse transfer conveyor below the discharge from the shredded refuse elevating conveyor. The collector is designed for an air flow of 56 m^3/min (2,000 ft^3/min) and a suction inlet pressure of 5 cm (2 in.) of water. The collector discharges the large dust particles to the kiln feed conveyor.

The kiln feed dust collector, located in the ram enclosure, has one collection point from the ram feed hoppers. The collector is designed for an air flow of 14 to 42 m^3/min (500 to 1,500 ft^3/min) at an inlet suction pressure of 25 cm (10 in.) of water. The large dust particles are discharged to the ground.

Operating Experience

The dust collecting system has performed poorly. A dust buildup of 2.5 cm (1 in.) per week is not uncommon in the areas serviced by the dust collection system. High velocities occur at the collection points causing entrainment of large particles, plugging of the rotary valves on the collectors, and deposits on the dust-collection fan, as discussed earlier. When plugging occurred, there was no access to the system to alleviate this problem, so access doors were installed in the dust collector, and quick-disconnect couplings were installed to allow dissembly of the duct for cleanout.

The double-acting flop gates on the collectors were changed to star rotary valves, and the angle of the discharge ducts from the dust collectors was increased to prevent plugging.

Originally, little could be done to control the flows from each collection point. This problem was solved by adding slide gates in the ducts.

The shredder inlet collection points were modified twice to prevent the pickup of large pieces of refuse. First screens were tried, but they plugged rapidly. Finally the inlet was changed to allow for rapid expansion of the flow area. The subsequent reduction in velocity then caused large refuse particles to settle out of the dust air stream.

The collection point at the discharge of the storage and recovery outfeed conveyor was disconnected because numerous jams occurred there and the collection hood limited access for clearing the jams.

Many of the dust collection ducts became plugged between the collection point and the dust separator because of the long ducts. The dust skirts at the conveyor transfer points were removed because they restricted the flow of refuse on the conveyor.

Maintenance

The preventive maintenance schedule for the dust collectors is shown in Table 64. Other maintenance for the dust collectors has mainly been to repair the drive for the rotary valves, sprockets, cams, and chains. The gear for one of the motors wore out and was replaced, and a bent driven shaft on one of the valves was straightened.

TABLE 64. DUST COLLECTOR PREVENTIVE MAINTENANCE SCHEDULE

Monthly

Check all rotary gates.
Check gearmotor oil.
    (Winter - EP5)
    (Summer - EP8)
Lubricate chain and linkages (Paradene 430).
Lubricate cams and followers (LiEP2).

Semiannually

Change gearmotor oil.
Check motor and alarm.
Check bearing condition and replace if necessary.

Annually

Megger motor.

Sump Pumps

The two storage pit sump pumps, located below each storage pit conveyor, pump the wash water from the receiving area to the sanitary sewer. The storage and recovery unit sump pump pumps wash and drain water from the outfeed conveyor tunnel to the sanitary sewer. The quench pit sump pump, located next to the residue quench tank, pumps process water from the quench pit area to the sanitary sewer.

Description

The sump pumps for the storage pit and for the storage and recovery unit are vertical with a design capacity of 378 lpm (100 gpm) at a total dynamic head of 12 m (40 ft) of water. These units are supplied by Swaby (Model 3B-3) and are designed to pump wastewater containing solids up to 2.5 cm (1 in.) in diameter. The pumps have local controls only and are provided with an on/off float control. The pumps are protected from solids plugging by a screen around the sumps that must be manually cleaned and by a purge stream of water from the discharge line to agitate settled solids.

The quench pit sump pump is vertical with a design capacity of 190 lpm (50 gpm) at a total dynamic head of 9 m (30 ft) of water. The pump is supplied by Swaby (Model BUL 4200) and is designed to pump wastewater containing solids. The pump has local controls only and is provided with an on/off float control.

Operating Experience

Originally, no screens existed around the sump pumps for the storage pit and the storage and recovery unit. But spillback from the storage pit conveyors plugged the pumps, causing overheating and failure. Installation of the screens helped, but they also plugged resulting in water accumulation.

Another problem with the pumps was that their discharge was lower than the sewage lift station, and the pumps had no check valves. When the lift station went out of service, the water backed up into the sumps. To solve this problem, the pump discharges were changed to be higher than the lift station.

The quench pit sump pump has continually failed as a result of the large solids concentration in the water. The quench pit sump has been cleaned and backflushed several times because of the solids accumulation within the sump.

Maintenance

Sump pump maintenance has mostly consisted of electrical repairs to the motors. Both of the storage pit sump pumps, which were grounded out after being submerged, were dried and reinsulated. The float switches also required repair or replacement. One of the storage pit sump pumps required new bearings, shaft, and bushings.

The preventive maintenance schedule for these pumps was shown in Table 36.

Wastewater Lift Station

The wastewater lift station receives the plant wastewater from the plant sewer system and pumps it to the city sewer system.

Description

The wastewater lift station is an Ecodyne package system consisting of a wet well, two sewage pumps, and a local control system. The local control system is made up of a hand/off/automatic switch for each pump, four level switches, and a base pump alternator. The four level switches include a low-level switch that shuts off all pumps, a middle switch that starts the base pump, a high-level switch that starts the high-level pump, and a high

high-level switch that sounds a local siren. Each of pump is designed for 946 lpm (250 gpm) at a total dynamic head of 11.4 m (38 ft).

Operating Experience

Even though the wastewater lift station is a standard package system, it was originally unreliable. After the pump gaskets and check valves were replaced and vacuum breaks were installed, the system was very reliable.

Maintenance

Since the above modifications were made, the unit has required only the preventive maintenance shown in Table 65.

TABLE 65. WASTEWATER LIFT STATION PUMPS PREVENTIVE MAINTENANCE SCHEDULE

Daily

Observe and check:
- Float switch, sewage pump, and vacuum priming operation.
- Mechanical seals.
- Water trap bottles.
- Cleanliness.

Monthly

Remove the electrode and clean any coatings and any deposits or scale from the electrode housing.
Replace electrode if more than half consumed.
Remove water trap bottles and clean out any water deposits in the jars. Lift the float mechanism to ensure that it is operating freely.
Check pumps and motors for vibration and abnormal heat.
Check seals for leaks.
Test check valves for proper seat.
Check floats and float switches.
Check starts, sequence timer, relays, etc.
Inspect and clean prime electrodes.
Check vacuum pump, ensure no vacuum leaks.

Semiannually

Lubricate blower bearing (Paradene 415).
Grease motors (LiEP2).
Check motor.

SECTION 3

MASS AND ENERGY BALANCE

INTRODUCTION

This section evaluates the operational efficiency of the Baltimore Landgard Plant in terms of mass and energy balances as derived from the characterizations (compositions and flow rates) of the plant's process streams. The balance data also serves as a means for performing an economic evaluation of the Baltimore plant and for guiding the design of future plants.

The information for preparing the mass and energy of balances was extracted from data gathered by Monsanto, the City of Baltimore, and SYSTECH. While TRW and the Environmental Elements Corporation also collected data, their data are not relevant to the mass and energy balances since they pertain to the particulate emissions at the gas purifier, boiler, and scrubber outlets. This information, however, is discussed in Section 4, Environmental Assessment, and is detailed in Appendix B.

The City of Baltimore has been continually recording operational data from the plant start-up to the present. Also from the plant start-up but only to February 1977, Monsanto conducted extensive sampling. SYSTECH's data sampling extended from November 1976 through June 1977 when an on-site team also monitored the entire plant operation. In addition, SYSTECH performed two one-week sampling batteries with a four-man team during June and August of 1977 to make its data bank more comprehensive.

To facilitate the preparation and presentation of the mass and energy balances, five of the plant's seven modules (see Section 2) were grouped in two operational categories: (1) waste preparation consisting of the receiving, the size reduction, and the storage and recovery modules and (2) thermal processing consisting of the thermal processing and the energy recovery modules. The sixth module in the Section 2 presentation, namely the Residue Separation module, is not included in this section since it was rarely used and its operation has been discontinued. The seventh module, namely the General Plant, is included in the discussion of the entire plant. Also to simplify the data evaluation, the sample data was normalized to an average refuse feed rate of 31.75 Mg/hr (35 tph).

For convenience, the modules in the respective operational categories are hereafter collectively referred to as subsystems, that is, the waste preparation subsystem comprising the receiving, the size reduction, and the storage and recovery modules, and the thermal processing subsystem comprising the thermal processing and the energy recovery modules.

This section briefly summarizes the sampling techniques and the process stream characterizations for each of the two subsystems and presents the mass and energy balances for the following: (1) the waste preparation subsystem; (2) the kiln, gas purifier, and waste heat boiler-economizer assembly within the thermal processing subsystem and the thermal processing subsystem itself; and (3) the entire plant. In addition, Appendix B presents the complete data sets, the detailed sampling and data reduction techniques, and other balances.

WASTE PREPARATION SUBSYSTEM

The incoming process streams (inputs) in this subsystem are refuse, diesel fuel, water, and electricity. While the refuse leaving the subsystem remains the same in quantity and composition as the refuse entering it, the mass and energy of the other process streams exit the subsystem as follows: The diesel fuel is used up by the storage pit bulldozers; the water supplied to cool the shredder bearings is discharged to the sewer; and the energy in the electricity used is dissipated to the ambient air.

As indicated by the encircled callout numbers in Figure 83, the refuse stream has been characterized at the following sampling points in the waste preparation subsystem: the truck scale, the storage pit, the storage pit conveyors, the shredded refuse conveyors, the storage and recovery unit, and the kiln feed conveyor. The sampling points and reference numbers in the following discussions correlate with the callout numbers in Figure 83.

The mass rates of the incoming and outgoing refuse are based on the weights read at the truck scale and the measurements taken by the belt scale on the kiln feed conveyor, respectively (see Figure 83, 1 and 2). While the rates may differ because of the varying refuse storage, the total mass of the incoming refuse eventually equals the total mass of the outgoing refuse.

The bulk density of the refuse at the various sample points was measured by weighting a known volume of refuse. Accordingly, the bulk densities were as follows for sample points 3, 4, 6, 8, and 10. In the storage pit (3), the bulk density of the refuse ranged from 144 kg/m^3 (9 lb/ft^3) for loose refuse to 498 kg/m^3 (31 lb/ft^3) for compact refuse. On the storage pit conveyor (4) before the refuse shredding, the average bulk density was 122 kg/m^3 (7.6 lb/ft^3); while on the shredded refuse elevating conveyor (6) after the refuse shredding the average bulk density was 50 kg/m^3 (3 lb/ft^3). Then in the storage and recovery unit (8), the bulk densities ranged from 200 kg/m^3 (12 lb/ft^3) for the waste normally transferred to the discharge conveyor to 400 kg/m^3 (25 lb/ft^3) for the refuse at the bottom of the piled waste. Finally, the bulk densities of the refuse leaving the silo on the kiln feed conveyor (10), varied as follows with the quantity of the refuse stored in the storage and recovery unit:

Storage (Mg)	Bulk Density (kg/m^3)
450 to 720	148
80 to 450	118
0	91

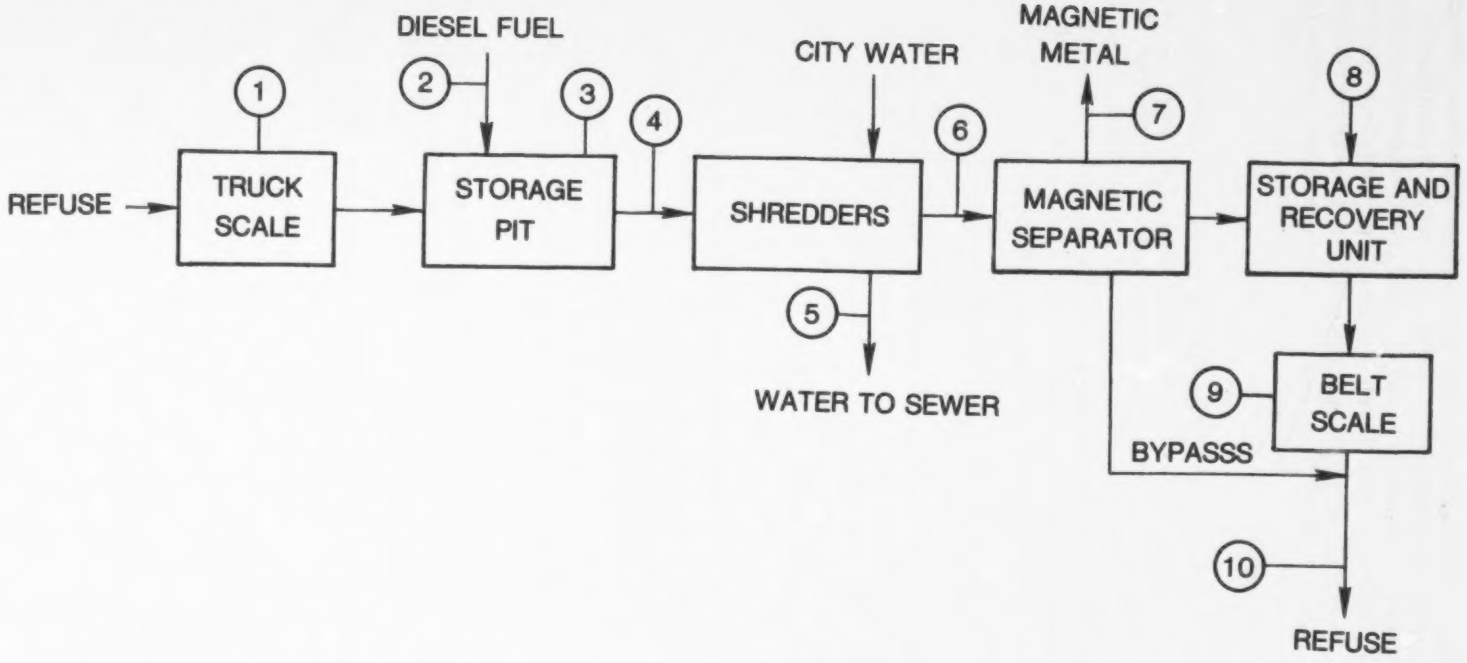

REFUSE
TRUCK SCALE
①
DIESEL FUEL
②
STORAGE PIT
③
④
CITY WATER
SHREDDERS
⑤
WATER TO SEWER
⑥
MAGNETIC METAL
⑦
MAGNETIC SEPARATOR
⑧
STORAGE AND RECOVERY UNIT
BELT SCALE
⑨
BYPASSS
⑩
REFUSE

Figure 83. Waste preparation subsystem sampling points.

The refuse particle sizes before and after the shredding process was determined by taking samples from the storage pit conveyor (4) and the shredded refuse elevating conveyor (6), respectively, and then measuring the sizes by sieve analysis. Both refuse streams had a wide range in size distribution. The nominal particle size (50 percent by weight finer) before shredding was 86 mm (3.5 in.), which is slightly larger than the nominal specification of 76 mm (3 in.) for the shredder discharge, and the nominal particle size after shredding was 13 mm (0.5 in.).

The composition of the unshredded refuse was determined by analyzing manual and photographic sorts of samples from the storage pit (3). Except for a higher concentration of glass, the composition of the Baltimore refuse compared closely with the average composition of the refuse in other cities, as indicated in Table 66. The composition of the shredded refuse was determined by performing proximate, ultimate, ash, and optical emission spectographic analyses of samples from the kiln feed conveyor (10). Table 67 summarizes the proximate, ultimate, and ash analyses detailed in Appendix B, which also includes the optical emission spectrographic data.

Since the magnetic metal separator has been discontinued, it is not included in the mass and energy balance. However, while it was operative, the metal recovered in the magnetic metal separator (7) was found to be 5.4 percent of the mass of the shredded refuse stream. A manual sort of one grab sample of the recovered metal revealed a metal purity of 88 percent with a recovery percentage of 68 percent.

The flow rate of the water to cool the shredder bearings was measured by clocking the time to fill a container of known volume with the water discharge to the sewer (5). The measured rate for each of the two shredders was 25.5 liters (6.7 gallons) per minute, or a total of 51 liters (13.4 gallons) per minute. The slight increase in the heat content (energy) of the cooling water through the shredders is assumed to be supplied by a portion of the electricity used by the shredder motor and is assumed to be lost to the surroundings.

As measured by a split core ammeter, the electric power consumed in the waste preparation subsystem averaged 476 kw, which equals an energy consumption rate of 28.6 MJ/min (0.027 M Btu/min).

The diesel fuel used by the storage pit bulldozers (3) was measured by daily reading the totalizer on the plant's diesel fuel pump. When refuse was being processed, the diesel fuel consumption averaged 208 liters (55 gallons) per day and 0.55 liter per Mg (0.13 gallon per ton) of refuse was processed over a range of refuse feed rates. When refuse was not being processed as during standby and downtime periods, the diesel fuel consumption averaged 64 liters (17 gallons) per day. Assuming a density of 0.87 kg/l (7.2 lb/gallon) and heat content of 45.2 MJ/kg (0.019 M Btu/lb), the diesel fuel mass and energy rates are 0.125 kg/min (0.275 M Btu/lb) and 5.7 MJ/min (0.005 M Btu/min), respectively.

TABLE 66. A COMPARISON OF REFUSE COMPOSITION

CATEGORY		BALTIMORE, MARYLAND*	ST. LOUIS, MISSOURI†	FRANKLIN, OHIO*	HEMSTEAD, NEW YORK§	NCRR¶	ERIE COUNTY, NEW YORK **
Paper	%	43	54	40	43	43	46
Inert	%	1		3		5	3
Glass	%	15	4	9	10	10	6
Metals	%	9	7	11	9	9	7
Organics	%	32	14	37	39	33	37
Miscellaneous	%		21				
Moisture (Wt %)		19	24				25
Bulk Density (kg/m^3)		122	122				163
Heating Value (MJ/kg)		9.3	10.7				10.8

*Values measured by Systech.

†Values from "St. Louis Demonstration Final Report: Refuse Processing Plant Equipment, Facilities, and Environmental Evaluations," by D.E. Fiscus, et. al., Midwest Research Institute, Kansas City, Mo., 19 March, 1976.

§Values from Municipal Refuse Disposal, Public Administration Service 1970, Interstate Printers and Publishers, Inc., Danville, Illinois.

¶Composition and Physical Characteristics," by Dah-Nien Fan, 1974 Summer Fellow, National Center for Resource Recovery, Inc., Washington, D.C.

**Values averaged form "Torrax- A Slagging Pyrolysis System For Converting Solid Waste To Fuel Gas," by John Z. Stoia, Operations Manager, Carborundum Environmental Systems, Inc., no date, covers period 1969-1973.

TABLE 67. REFUSE COMPOSITION

Analysis	Minimum		Average		Maximum	
	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry
Proximate (%)						
Moisture	8.50	--	19.47	--	39.70	--
Volatile Matter	20.46	25.49	37.54	46.80	57.51	75.18
Fixed Carbon	1.13	1.28	6.69	8.36	21.55	26.85
Ash	8.27	10.31	36.29	44.80	54.73	63.35
Sulfur	0.05	0.07	0.13	0.16	0.18	0.23
Heat Content (MJ/kg)	6.02	6.80	9.31	11.61	13.06	14.49
Ultimate (%)						
Carbon		20.31		31.07		40.67
Hydrogen		0.46		1.95		5.58
Nitrogen		0.19		2.32		6.65
Oxygen		5.80		19.76		42.09
Ash (%)						
Aluminia		1.11		11.52		44.85
Chromic Oxide		0.04		0.04		0.04
Cupric Oxide		0.11		0.11		0.11
Ferric Oxide		1.73		14.77		64.78
Lead Oxide		0.11		0.11		0.11
Lime		2.51		5.75		11.51
Manganese Dioxide		0.11		0.11		0.11
Magnesia		0.29		0.79		1.60
Nickel Oxide		0.01		0.01		0.01
Phosphorous Pentoxide		0.35		0.55		0.66
Potassium Oxide		0.22		0.58		1.05
Silica		26.12		55.21		74.80
Sodium Oxide		2.05		5.60		9.00
Sulfur Trioxide		0.29		0.51		0.63
Titania		0.40		0.52		0.75
Zinc Oxide		2.02		2.02		2.02

Noise levels within the plant were measured by a hand-held noise meter. Dust levels in the receiving building, shredder buildings, and storage and recovery unit were measured with a low-volume personnel sampler. In addition, a grab sample of dust from one shredder building was analyzed for bacteria concentrations. Gas concentrations in the receiving building air were measured by Monsanto with gas tech tubes and by SYSTECH with an automatic carbon monoxide detector. The resultant environmental data are presented and discussed in Section 4, Environmental Assessment.

Figure 84 presents the mass and energy balance for the waste processing subsystem. This figure assumes the following: (1) all the refuse changed negligibily in mass and heat content while passing through the subsystem; (2) the mass and energy of the diesel fuel was lost, as work and heat, to the surroundings; and (3) the heat generated by the electric power was dissipated to the surroundings. The energy efficiency of the subsystem (the quotient of the output energy in the refuse, divided by the input energy in the refuse, diesel fuel, and electricity) was 99.2 percent.

THERMAL PROCESSING SUBSYSTEM

The incoming process streams (inputs) to this subsystem include refuse, fuel oil, propane, air, water, boiler feedwater chemicals, and electricity. The outgoing process streams (outputs) from this subsystem include kiln residue, gas purifier slag, boiler fly ash, stack gases with entrained particulate, wastewater, steam, and low-grade heat lost to the atmosphere.

The encircled callout numbers in Figure 85 indicate the sampling points for the process streams in the thermal processing subsystem. As for the waste preparation subsystem, the sample points and reference numbers in the following discussions correlate with the callout numbers in this figure.

At the outset of SYSTECH's characterizing the Baltimore plant process, the intent was to take a sufficient number of measurements to verify Monsanto's process balances. However, it soon became apparent that SYSTECH would have to acquire independent data because of the process and equipment changes made after the Monsanto data were collected. Moreover, the Monsanto data did not approximate the simultaneous measurements required for a process balance.

Since the variation of the refuse composition and feed rate and of the process operation made it difficult to calculate an adequate mass and energy balance for the thermal processing subsystem, a balance was developed for a standby condition with no refuse flow to provide controlled data points. The controlled data points were sought in order to acquire data for points that are very difficult to measure, such as the quench air flow and the gas purifier heat transfer.

Of all the SYSTECH tests, only one was conducted while the refuse stream flowed to the storage and recovery unit. Nevertheless, the refuse feed rate was therefore known while approximately steady-state conditions prevailed. Consequently, a balance for this test was developed by working from the boiler discharge (20) backwards through the thermal processing

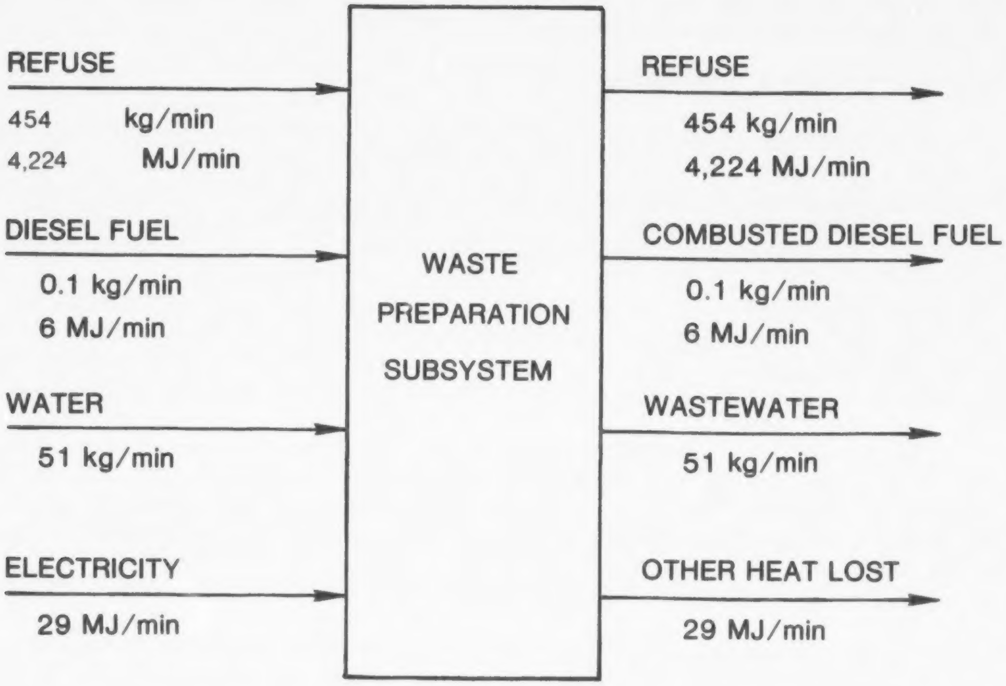

REFUSE
454 kg/min
4,224 MJ/min
DIESEL FUEL
0.1 kg/min
6 MJ/min
WATER
51 kg/min
ELECTRICITY
29 MJ/min
WASTE
PREPARATION
SUBSYSTEM
REFUSE
454 kg/min
4,224 MJ/min
COMBUSTED DIESEL FUEL
0.1 kg/min
6 MJ/min
WASTEWATER
51 kg/min
OTHER HEAT LOST
29 MJ/min

Figure 84. Waste preparation subsystem mass and energy balance.

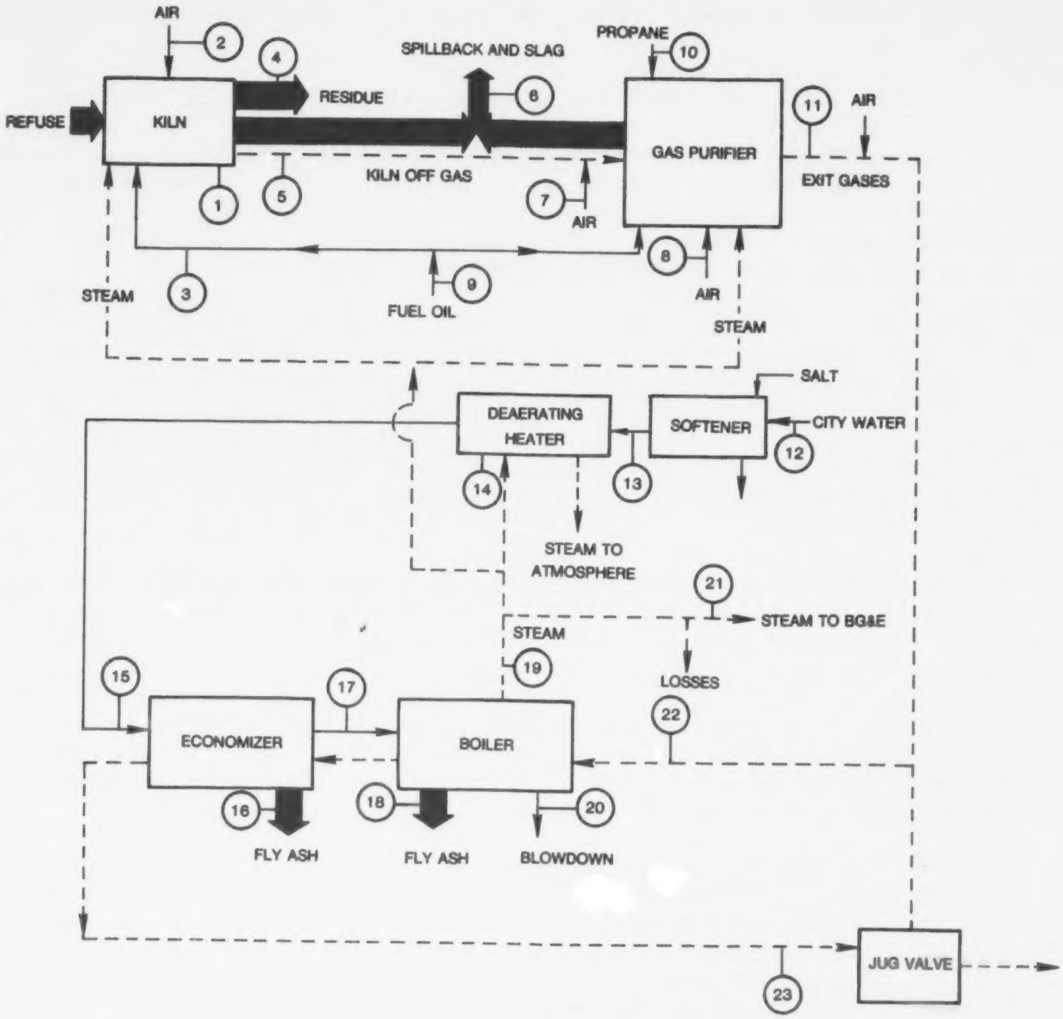

AIR
2
4
SPILLBACK AND SLAG
PROPANE
10
REFUSE
KILN
RESIDUE
6
11
AIR
GAS PURIFIER
EXIT GASES
1
5
KILN OFF GAS
7
AIR
8
STEAM
3
9
FUEL OIL
AIR
STEAM
SALT
DEAERATING HEATER
SOFTENER
CITY WATER
12
14
13
STEAM TO ATMOSPHERE
21
STEAM
STEAM TO BG&E
19
LOSSES
15
17
22
ECONOMIZER
BOILER
16
18
20
FLY ASH
FLY ASH
BLOWDOWN
JUG VALVE
23

Figure 85. Thermal processing subsystem sampling points.

subsystem. The boiler discharge was selected as the starting point since its measurement is considered the most accurate and reliable of all the gas flow measurements. Then all inputs to the subsystem were summed with leakage air calculated by forcing the balance. Only a small error was introduced by so forcing the balance since the leakage was less then 3 percent of the total subsystem input.

Then the data for the other SYSTECH tests were analyzed and evaluated according to the estimated refuse feed rates and the average values for the proximate and ultimate refuse analyses. The estimated feed rates were based on the average shredder discharge of 31.75 Mg/hr (35 tph) and the refuse levels observed on the shredded refuse conveyors. Next, from the data measured and derived, both a mass and an energy balance for the thermal processing subsystem were prepared from the data for each test. In the resultant mass balances, the mass outputs deviated from the mass inputs by 3.65 percent on the average. Most of the mass output deviations were within 3 percent of the mass inputs. In the resultant energy balances, the deviations of the energy outputs from the energy inputs ranged from 1.4 to 19 percent, with most of the energy output deviations being within 10 percent of the energy inputs. Finally, to prepare the mass and energy balances for the kiln, gas purifier, boilers, and total plant, the seven SYSTECH tests that had estimated refuse feed rates of 530 kg/min (35 tph) were selected and their data were averaged.

Appendix B presents the Monsanto data along with the resultant mass and energy balances. In the development of these balances, the mass balances were first prepared by selecting tests with the most complete data and then adjusting reasonable estimates for the unmeasured flow rates according to the known data for a perfect balance of the mass inputs and mass outputs. Then from the perfect mass balances, the energy balances were calculated. In the resultant energy balances, the deviations of the energy outputs from the energy inputs ranged from 0.1 to 7.1 percent, and the standard deviation was 2.3 percent which reflects good agreement for field measurements.

In the following paragraphs, the process stream characterizations, that is, compositions and flow rates, are generally ordered according to their interrelationships as well as their relevance to the sequence of the mass and energy balance presentations. Therefore, preparatory to the presentation of the mass and energy balance for the kiln, the next paragraphs deal with the composition and flow rates of the process streams pertinent to the kiln except for the incoming refuse which was detailed in the preceding section for the waste preparation subsystem.

While the fuel oil composition was determined by two ultimate analyses which are detailed in Appendix B, the fuel oil flow rates were computed from hourly and daily readings of the totalizer (9) which measured the fuel oil flow to the fuel oil pumps. During normal operation, the process burners are usually set at a fixed firing rate. Consequently, their fuel oil consumption is independent of the amount of refuse processed. However, because of the different burner tips and minimum firing rates during the successive evaluation periods, the fuel oil consumption varied as summarized below:

Period	Consumption (l/hr)
11/01/76 to 12/21/76	738
01/18/77 to 03/11/77	265
03/05/77 to present	600

The flow rate of the fuel oil to the two main kiln burners (3) was registered by a flow indicator on the main control panel. The fuel oil flows to the kiln safety burners, the slag hole fuel oil burner, and the gas purifier pilot burner were known since these burners have fixed firing rates. While the gas purifier heatup burner is generally used only during standby and heatup operations and the fuel oil flow to it is varied, its flow rate was computed by subtracting the sum of the other burner flow rates from the total fuel oil consumption rate. During standby operation, the fuel oil consumption averaged 3,000 l/hr (800 gal/hr). The firing rates for the various burners were discussed in the previous section. For the balance, the density and heat content of the fuel oil were assumed to be 0.892 kg/l and 45.5 MJ/kg.

The flow rate of the propane used by the two slag tap hole burners (21) was determined by monitoring the propane deliveries to the plant and then dividing the total quantity of propane received by the number of hours between deliveries. The average propane consumption rate was 155 l/hr. For the balance, the density and heat content of the propane was assumed to be 2 g/l and 50.2 MJ/kg, respectively.

Except for the airflow rates through the dust collection fan and the quench air dampers, the flow rates of the combustion air were measured by a hand-held anemometer at the fan inlet cowls (2, 7, and 8). The flow rate for the air flow through the dust collection fan was measured by a pitot tube inserted into the fan discharge duct, and the flow rate of the airflow through the quench air dampers is discussed later. Although the airflow rates through the process fans, except the dust collection fan, were varied considerably, the following approximate rates were typical when refuse was being processed:

Fan	Flow (CMM)
Refuse combustion air fan	350
Turbine-driven kiln combustion fan	200
Motor-driven kiln combustion fan	500
Gas purifier combustion air fan	200
Crossover dust combustion air fan	450
Dust collection fan	365

The leakage air, calculated as previously discussed, was included in each of the balances.

Most of the water input to the thermal processing subsystem is consumed as boiler feedwater. Varying directly with the steam production rate, the flow rate of the boiler feedwater was monitored by observing the flow indicators in the control room or the totalizer on the water softeners (11). The flow rate of the cooling water to the induced-draft fan bearing was measured by clocking the time to fill a container of known volume with the water discharged from the fan bearing to the sewer. Design data were used to estimate the flow rate of makeup water fed to the recycled cooling water system. The flow rates of the water for the gas scrubber operation and for the gas purifier cooling are not included since the gas scrubber is being replaced by an electrostatic precipitator and the gas purifier cooling is not representative of normal operation. Monsanto determined the flow rates of the makeup water for the residue quench tank and the seal tank by noting the changes in the water levels of the tanks while the makeup water to the tanks was turned off for a specific time period. The calculation of the boiler chemical consumption was based on the design concentration and the boiler feedwater flow rates.

The electrical power consumption of the subsystem was computed by measuring the power consumed by the individual pieces of equipment with a split core ammeter and then summing the measurements. Then considering that the gas scrubber would be replaced by the electrostatic precipitator with an assumed power consumption of 500 kw, the total electric power consumption was estimated to be 1,500 kw while refuse was being processed, which equals an energy consumption rate of 84 MJ/min.

The skin temperatures of the various vessels and ducts were measured by a portable surface contact pyrometer and a portable optical pyrometer. This could not be done for the gas purifier since it was cooled by random water streams. The skin heat loss for the gas purifier was calculated using the "standby" balance as discussed above.

The flow rate of the kiln residue was computed as a fraction of the flow rate of the shredded refuse by dividing the net weight of the residue as measured on the residue trucks during a given period by the net weight of the shredded refuse as measured by the belt scale on the kiln feed conveyor during the same period. Although the residue flow rate varied considerably, it was 44 percent of the refuse flow rate on the average.

The kiln residue samples for the composition analysis were collected in a bucket as the residue fell through the bypass opening in the residue conveyor. As routinely determined, the moisture content and bulk density of the residue were on the average 31 percent and 1,600 kg/m^3 (100 lb/ft^3) respectively. Table 68 summarizes the proximate, ultimate, and ash analyses for the residue. Sieve analysis of the residue revealed that on the average only 3 percent of the residue by weight had a particles size larger than 102 mm (4 in.) and 62 percent had a particle size smaller than 5 mm (0.2 in.). Most of the larger particles were metals such as cans and scrap pieces. The fluid ash fusion temperature of the residue was about 1100°C (2000°F).

TABLE 68. RESIDUE COMPOSITION

	Minimum		Average		Maximum	
	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry
Proximate (%)						
Moisture	0.10	--	27.34	--	51.66	--
Volatile Matter	0.00	0.00	3.88	5.74	8.33	12.20
Fixed Carbon	0.09	0.10	4.20	6.75	28.62	55.01
Ash	15.08	28.98	64.65	87.52	94.74	98.53
Sulfur	0.01	0.01	0.11	0.16	0.26	0.27
Heat Content (MJ/kg)	0.59	0.73	2.43	3.90	4.07	7.03
Ultimate (%)						
Carbon		3.00		6.82		15.48
Hydrogen		0.08		0.23		0.35
Nitrogen		0.07		0.37		1.23
Oxygen		<0.09		1.01		2.08
Ash (%)						
Aluminia		2.58		3.80		4.91
Ferric Oxide		1.61		13.74		43.58
Lime		2.89		4.97		6.15
Magnesia		0.46		0.69		0.85
Phosphorous Pentoxide		0.30		0.63		0.89
Potassium Oxide		0.29		0.52		0.74
Silica		38.76		62.67		75.40
Sodium Oxide		3.82		6.73		12.12
Sulfur Trioxide		0.51		0.55		0.58
Titania		0.18		0.75		2.03

During mid 1975, Monsanto extensively sampled the kiln-off gas at the feed hood (2). The gases were characterized by orsat readings and several methods to define the particulate loadings, size distribution, and composition. However, since the data were acquired under conditions different from the present conditions because of the subsequent operational changes in the kiln, the data is presented only in Appendix B.

Four methods were used to analyze the composition of the kiln-off gas in the crossover duct (5). While Monsanto conducted a mass spectrographic analysis, SYSTECH used orsat measurements and gas chromatography (flame ionization detection and thermal conductivity) for the composition analyses. Table 69 summarizes the average values obtained by each of the four methods. The values for the mass spectrographic analysis differ from those for the orsat measurements and the thermal conductivity analysis primarily because of the changes in the kiln operation. The low values for the flame ionization detection analysis were probably due to a leak in the sampling line.

TABLE 69. KILN-OFF GAS COMPOSITION (VOLUME %)

Gas	ANALYSIS			
	Mass Spectographic	Orsat	Flame Ionization Detection	Thermal Conductivity
Nitrogen	61.99	---	---	60.4
Carbon Dioxide	13.57	14.42	---	12.1
Hydrogen	9.16	---	---	*
Carbon Monoxide	10.03	5.62	---	7.3
Oxygen	2.21	0.90	---	1.2
Methane	1.46	---	0.20	0.97
Argon	0.67	---	---	---
Ethylene	0.32	---	0.06	---
Acetylene	0.10	---	---	---
Ethane	0.09	---	0.01	---
Benzene	0.04	---	---	---
Propane	---	---	0.01	---
iso-Butane	---	---	0.00	---
n-Butane	---	---	0.01	---

*Interference

The long-chain hydrocarbon oil and grease concentrations in the kiln-off gas were measured by first passing a known volume of the gas through a series of impingers containing xylene. Then after the oil and grease concentration in an aliquot was determined by gas chromatography, the total oil and grease collected was calculated by multiplying the concentration by the total volume of the xylene impinger solution. Finally, the total oil and grease was divided by the toal volume of an air sample measured by a dry gas meter. The oil and grease concentrations in the kiln-off gas averaged 5 mg/m^3 (215 mg/ft^3). The heating value of the kiln-off gas (5) in the crossover duct was 3.4 MJ/m^3 (92 Btu/ft^3) on the average. The calculations were based on the more complete mass spectrographic analysis and the foregoing oil and grease data with the assumption that the oil and grease had a heating value of 39.5 MJ/kg (17,000 Btu/lb).

The temperaute of the kiln-off gas (5) in the crossover duct was measured by a portable SYSTECH thermocouple and checked with a city thermocouple permanently installed inside the fire hood. The temperatures generally ranged from 650°C (1200°F) to 1100°C (2000°F) and averaged about 815°C (1500°F).

The velocity of the kiln-off gas (5) in the crossover duct was measured by a 1.5 m (5 ft) s-type pitot tube and a horizontal oil-filled manometer. The flow rates of the kiln-off gas averaged 1,615 kg/mm (3,553 lb/min) during seven SYSTECH tests when the refuse feed rate was approximately 31.75 MG/hr (35 tph).

The flow rate of the atomizing steam used by the kiln burners was assumed to be 18 kg/min (40 lb/min) on the basis of design data. While the kiln temperature of the kiln shell varied considerably, they averaged about 175°C (350°F). The flow rate of the water evaporating from the residue quench tank and the seal tank was estimated as 5 kg/min (11 lb/min), and the flow rate of the spillback into the seal tank as only about 0.5 kg/min (1 lb/min).

Figure 86 presents a typical kiln mass and energy balance. This balance is based on the seven SYSTECH tests when the refuse feed rate was estimated to be 530 kg/min (35 tph). The reference point for the energy calculations was 0°C (32°F). On the basis of this balance, the kiln energy efficiency (the quotient of the energy in the kiln-off gas divided by the total input energy) was 72 percent.

Before the gas purifier vessel was rebricked and randomly water-cooled, the average skin temperatures increased from 200°C (400°F,) to 350°C (650°F) as the refractory thickness decreased.

As continually measured by weighing each truck load of slag (16), the flow ratio of the slag emitted from the gas purifier averaged 1.77 percent of the refuse input rate on a wet-to-wet basis and 1.93 percent on a dry basis.

To collect samples for the slag composition analysis, a bucket was placed in the slag trucks at a position directly under the discharge of the

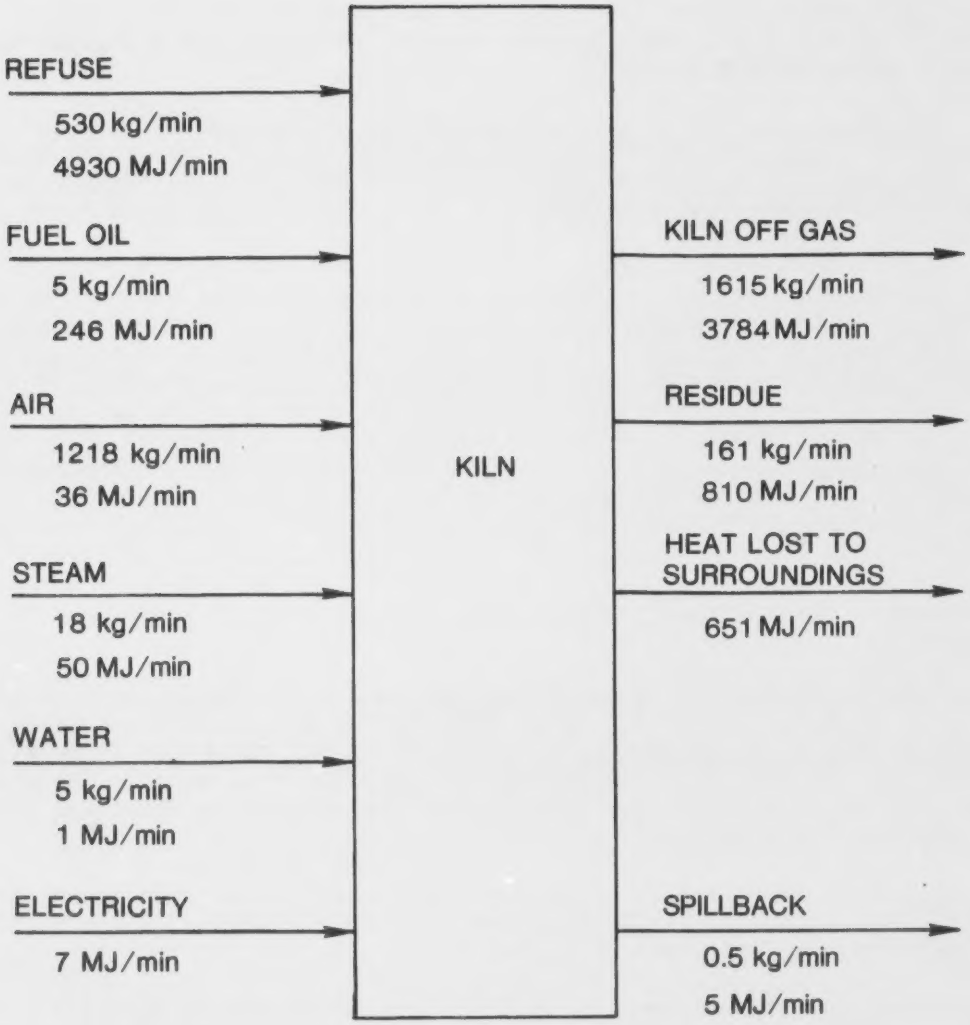

REFUSE
530 kg/min
4930 MJ/min
FUEL OIL
5 kg/min
246 MJ/min
AIR
1218 kg/min
36 MJ/min
STEAM
18 kg/min
50 MJ/min
WATER
5 kg/min
1 MJ/min
ELECTRICITY
7 MJ/min
KILN
KILN OFF GAS
1615 kg/min
3784 MJ/min
RESIDUE
161 kg/min
810 MJ/min
HEAT LOST TO SURROUNDINGS
651 MJ/min
SPILLBACK
0.5 kg/min
5 MJ/min

Figure 86. Kiln mass and energy balance.

slag conveyor. The moisture content and the bulk density of the slag were on the average 14 percent and 1690 kg/m^3 (106 lb/ft^3), respectively. As measured by sieve analysis, more than 80 percent of the slag particles were smaller than 5 mm (0.2 in.) which indicates that the slag generally fritted into fine particles.

The average ash chemistry of slag is shown in Table 70, while the ash chemistries and spectrographic analyses of various slag samples are detailed in Appendix B and Section 4, Environmental Assessment, respectively. The fluid ash fusion temperature of the slag was about 1350°C (2460°F) for samples taken by Monsanto and 1100°C (2000°F) for samples taken by SYSTECH. While Section 4 presents the results of a slag leachate test, Appendix B discusses the test procedure.

TABLE 70. AVERAGE ASH CHEMISTRY OF GAS PURIFIER SLAG

Constituent	Percent by weight
Alumina	15.13
Carbon	0.10
Chromic oxide	0.05
Ferric oxide	3.57
Lime	9.22
Magnesia	1.83
Nickel oxide	0.06
Phosphorous Pentoxide	2.27
Potassium oxide	1.56
Silica	55.98
Sodium oxide	4.50
Stannic oxide	0.23
Sulfur trioxide	0.16
Titania	2.38
Zinc oxide	0.34

To determine the composition of the gas purifier exit gas (11), SYSTECH utilized orsat measurements, and Monsanto performed spectrographic and total hydrocarbon analyses. Table 71 presents the average gas composition. The SYSTECH data indicates that the gas purifier operation was near the stoichiometric level. The higher oxygen levels in the Monsanto data were probably due to the data being collected during standby conditions.

As measured by a permanently installed thermocouple in the gas purifier, the temperature of the gases exiting the gas purifier was generally about 1300°C (2350°F).

TABLE 71. COMPOSITION OF GAS PURIFIER EXIT GASES

	Orsat (Vol %)	Mass Spectographic	Total Hydrocarbons ($\mu\ell/\ell$)
Nitrogen	-	78.5	-
Carbon dioxide	12.6	5.0	-
Oxygen	0.3	14.7	-
Carbon monoxide	1.8	1.7	-
Hydrogen	-	1.0	-
Methane	-	Trace	1.0
Total hydrocarbon as (CH_4)	-	-	38.0
Argon	-	0.8	-

As for the kiln-off gas, a 1.5-m (5-ft) S-type pitot tube and a horizontal oil-filled manometer were used to measure the flow rate of the gas purifier exit gas (11). On the average, the flow rate was 2670 kg/min (5874 lb/min) during the seven SYSTECH tests when the average refuse feed rate was 530 kg/min. (35 tph).

On the basis of the design data, the flow rate of the atomizing steam used by the gas purifier burners was estimated to be 7 kg/min (15 lb/min), and the flow rate of the water evaporating from the seal tank at the slag tap hole was estimated to be 8 kg/min (18 lb/min). The characterization of the propane stream is not presented in this section since the propane stream effects on the mass and energy balances would be negligible.

Figure 87 presents a typical gas purifier mass and energy balance which is also based on the seven SYSTECH tests. On the basis of this balance, the gas purifier energy efficiency (the quotient of the energy in the gas purifier exit gas divided by the total input energy) was 84 percent.

The flow rate of the air entering the gas purifier outlet through the slotted and the butterfly quench air dampers in the gas purifier exit duct was calculated on the basis of the duct opening and the pressure differential. While the slotted damper was always completely open and the air flow through it therefore varied with differential pressure only, the butterfly damper opening was regulated and the air flow through it varied with both the damper setting and the differential pressure. Accordingly, a set of flow rate curves was prepared for both dampers. The curves are presented in Appendix B. From these curves, the flow rate of the air through the dampers was estimated to be 1055 kg/min (2322 lb/min) when the average refuse feed rate was 530 kg/min (1166 lb/hr, or 35 tph). The mixture of the gas purifier exit gas and the air entering the gas purifier outlet through the quench air dampers became the boiler inlet gas discussed in the next paragraph.

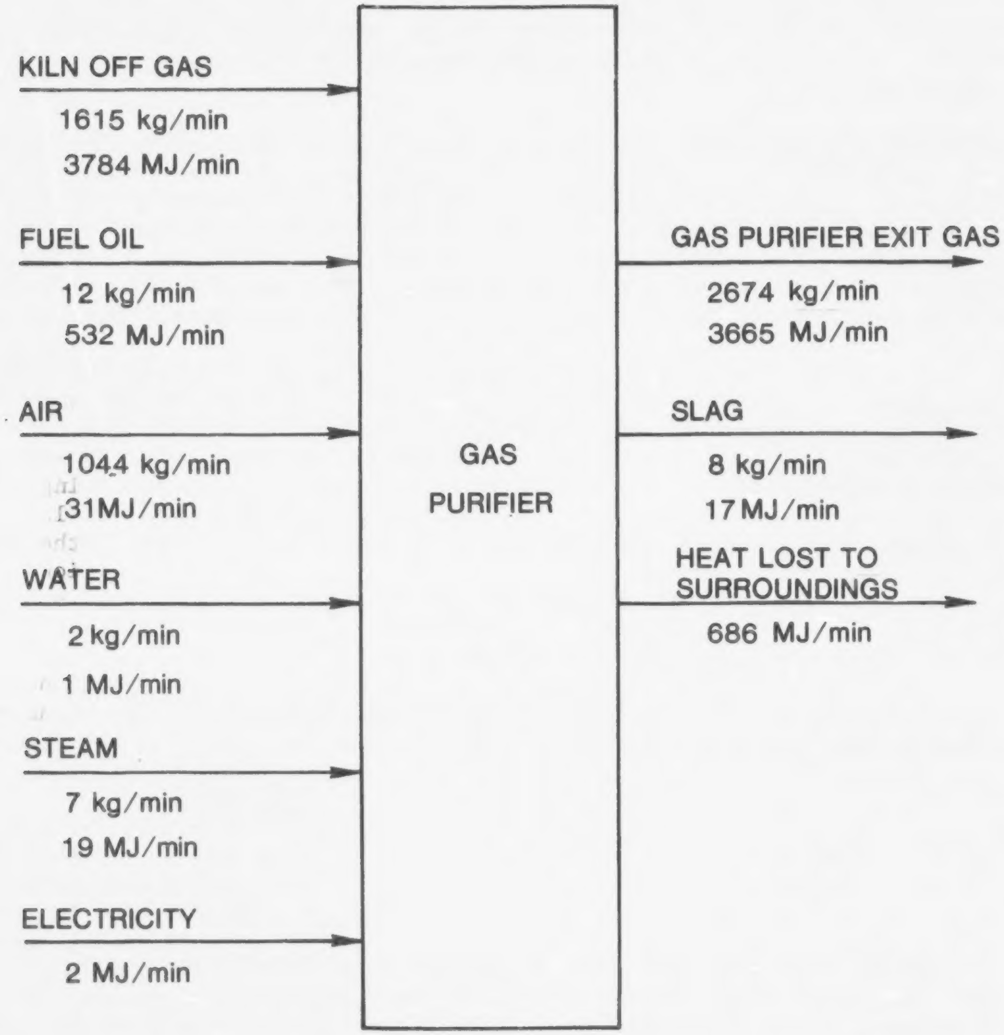

KILN OFF GAS
1615 kg/min
3784 MJ/min
FUEL OIL
12 kg/min
532 MJ/min
AIR
1044 kg/min
31MJ/min
WATER
2 kg/min
1 MJ/min
STEAM
7 kg/min
19 MJ/min
ELECTRICITY
2 MJ/min
GAS
PURIFIER
GAS PURIFIER EXIT GAS
2674 kg/min
3665 MJ/min
SLAG
8 kg/min
17 MJ/min
HEAT LOST TO
SURROUNDINGS
686 MJ/min

Figure 87. Gas purifier mass and energy balance.

The analysis of orsat measurements revealed that the boiler inlet gas (13) had the following approximate composition:

	Volume (%)
Carbon dioxide	8.5
Oxygen	8.7
Carbon monoxide	0.0

These volume percentages indicate that the quench air provided sufficient excess air (67 percent) to complete the gas combustion. A permanently installed thermocouple provided measurements of the boiler inlet gas (13) temperature.

Like the procedure for the kiln residue characterization, the flow rate of the boiler (18) and economizer (16) fly ash was computed as a fraction of the flow rate of the shredded refuse by dividing the net weight of the fly ash collected in the drums under the fly ash hoppers during a given period by the net weight of the shredded refuse transported on the filn feed conveyor during the corresonding period. The average flow rate of the fly ash was 0.09 percent of the refuse flow rate on a wet basis and 0.011 percent on a dry basis.

To collect fly ash for the composition analysis, a sample was taken from each drum in proportion to the amount of fly ash in the drum and then the samples were composited. The bulk density of the fly ash was 880 kg/m^3 (55 lb/ft^3). Since much of the fly ash had agglomerated, the individual particle sizes could not be determined. However, the agglomerated pieces had the following size distribution: 76 percent were smaller than 5 mm, 20 percent were between 5 and 25 mm, and 4 percent were between 25 and 50 mm.

The fluid ash fusion temperature of the boiler fly ash was 1190°C (2175°C). Section 4, Environmental Assessment, discusses the ash chemistry and the analysis of the aqua regina solubles for the boiler fly ash.

The analysis of orsat measurements revealed that the boiler exit gas (20) had the following approximate composition:

	Volume (%)
Carbon dioxide	8.1
Oxygen	9.5
Carbon monoxide	0.6

While data gathered by the Environmental Elements Corporation indicate that the moisture content of the gas at the boiler discharge (21) was about 20 percent, measurements taken by SYSTECH show that it was about 12 percent.

Again with a 1.5-m (5-ft) S-type pitot tube and a horizontal oil-filled monometer to measure velocity, the flow rate of the gas in the boiler discharge (21) duct was on the average 3730 kg/min (8205 lb/min) during the seven SYSTECH tests when the average refuse rate was 530 kg/min (35 tph).

As measured by a portable thermocouple with a dial gauge, the temperature of the boiler discharge gas was 190°C (375°F) on the average. Appendix B presents the ash chemistries of the particulate in the boiler exit gas.

The city water (12) was sampled twice to verify that the water is low in total solids (138 mg per liter) and in hardness (77 mg per liter) as determined in analyses by the Purification Section, Water Division, Bureau of Operations, Department of Public Works, City of Baltimore. The boiler feedwater (13), the boiler water (20), and the constant blowdown from the boiler steam drums were also sampled. While the total solids concentration in the boiler feedwater was approximately the same as that in the city water, the hardness of the boiler feedwater was virtually zero. Since the boiler water and the constant blowdown each had a total solids concentration of about 1130 mg, the blowdown rate was about 10 percent of the feedwater rate, which is the Monsanto design value. The boiler water and constant blowdown has a pH of 10.5 and an alkalinity concentration of 400 per liter. The iron concentration in the constant blowdown was much higher than that which could be accounted for by the iron concentration in the boiler feedwater.

As derived from readings of both flow meters in the control room and totalizing flow meters on the water softeners, the flow rate of the boiler feedwater was approximately 1226 kg/min (2698 lb/min) during the seven SYSTECH tests.

On the basis of readings of the dials mounted on the deaerating tank, the temperature and pressure of the feedwater in the deaerating heater (14) were generally 106°C (222°F) and 34.5 kPA (5 psig), respectively. From calculations based on the cross-sectional area of the heater vent opening and the pressure differential between the vessel and the atmosphere, the steam loss through the vent was 5 kg/min (11 lb/min). The skin temperature of the deaerating heater was 93°C (200°F) on the average according to the measurements of a surface contact pyrometer. The feedwater temperature at the economizer outlet (17), as read from permanently installed dial thermocouples, was generally 208°C (407°F). On the basis of this temperature, the economizers accounted for about 20 percent of the waste heat recovered by the boiler-economizer assemblies.

While the flow rate of the steam from each boiler (19) was read from the meters in the control room, the flow rate of the steam from both boilers as delivered to the local utility company was read hourly on the company's totalizing meter and transmitted to the Landgard plant. The steam delivered to the utility company was 1028 kg/min (136,000 lb/hr) on the average. Calculated as a function of the boiler operating pressure, the line losses in the steam main from the plant to the company averaged 32 kg/min (70.4 lb/min). The atomizing steam used in the mass and energy balance is the sum of the atomizing steam used by the kiln and gas purifier burners. Since the motor-driven feedwater pump was on line during most of the test evaluation periods, this pump is represented in the balance calculations rather than the turbine-driven feedwater pump.

Figure 88 presents a typical boiler mass and energy balance. Like the previous balances, this balance is based on the seven SYSTECH tests. On the basis of this balance, the boiler energy efficiency (the quotient of the energy in the generated steam divided by the energy in the boiler inlet gas and feedwater) was 77 percent.

Figure 89 presents a typical mass and energy balance for the entire thermal processing subsystem. According to this balance, also based on the SYSTECH data, the energy efficiency of the subsystem was 49 percent.

For the following discussion preparatory to the presentation of the typical total plant mass and energy balance, the plant inputs are refuse, air, water, fuel oil, gasoline, diesel fuel, propane, electricity, and boiler chemicals. Also, the plant outputs are stack gas, kiln residue, gas purifier slag, fly ash, wastewater, steam, and lost heat. Although the plant balance excludes the residue separation module and the gas scrubber for the reasons cited above, Appendix B presents the process stream characterizations for these two units. Also as stated above, the balance calculations include the 300 kw assumed for the electrostatic precipitator which is replacing the gas scrubber.

As computed from daily readings of the main water meters on the plant boundary, the average flow rate of the city water used by the entire plant was 1448 lpm (383 gpm). The flow rate of the wastewater discharged from the plant was 242 lpm (63 gpm) on the average. This flow rate was computed by clocking the time to fill the wet well of the wastewater lift station while the lift pump was turned off. The averages of measured temperatures and pH's of the wastewater were 40°C (104°F) and 10.5, respectively.

Appendix B and Section 4, Environmental Assessment, present and discuss respectively, the results of the analyses of grab samples of the wastewater and various other process water streams.

The data to compute the total plant electrical power consumption consisted of the measurements of the individual units taken with the split core ammeter and the 15-minute computer printouts generated and provided by the Baltimore Gas and Electric Company. The average electrical power consumption was 142 kw during downtime, 1109 kw during standby operation, and 1800 kw during normal plant operation. The projected total plant power demand when the electrostatic precipitator has replaced the gas scrubber is 2200 kw.

The flow rate of the plant gasoline, used mainly by the residue trucks, was computed from daily readings of the totalizer on the gasoline pump. The average gasoline consumption was 620 lpd (164 gpd) during normal plant operation and 93 lpd (25 gpd) during downtime.

Figure 90 presents a typical total plant mass and energy balance, which is also based on the seven SYSTECH tests. Based on this balance, the total plant energy efficiency (the quotient of the output energy in the delivered steam divided by the total input energy) was approximately 46 percent.

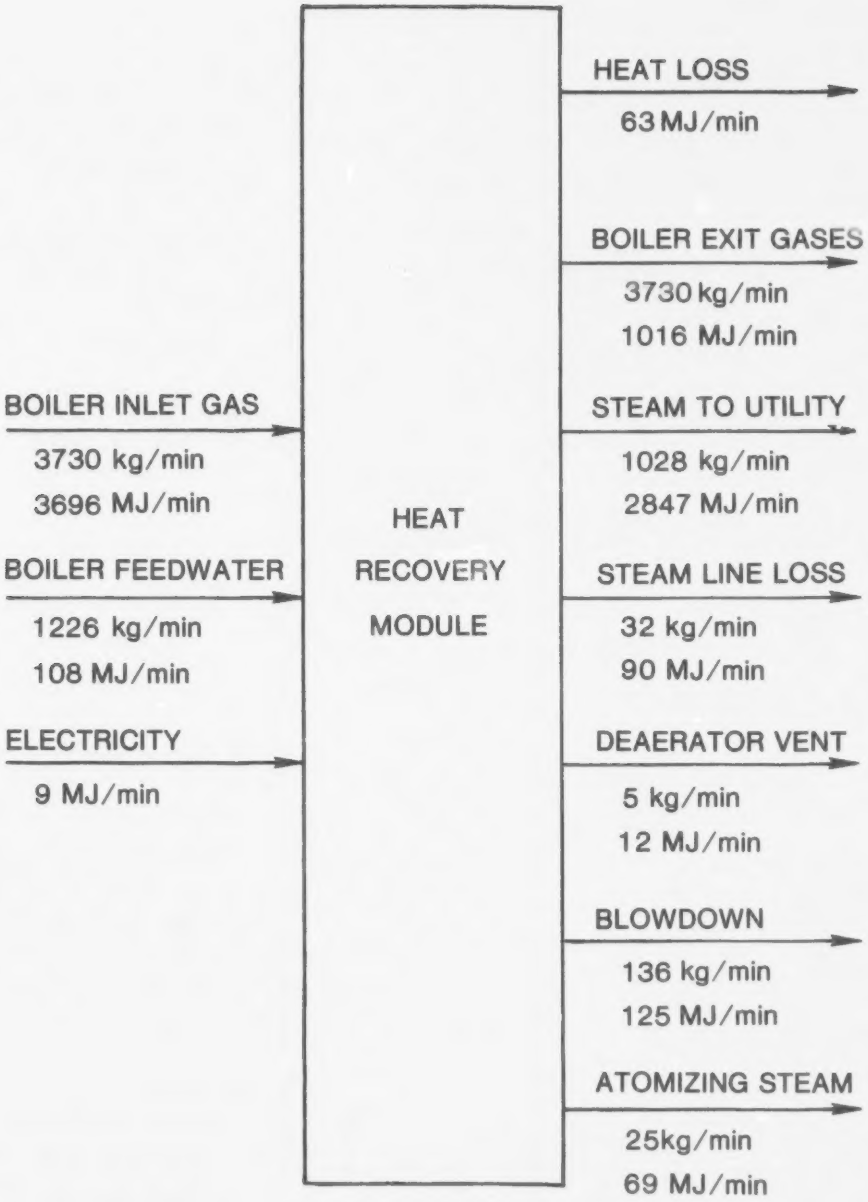

HEAT LOSS
63 MJ/min
BOILER EXIT GASES
3730 kg/min
1016 MJ/min
BOILER INLET GAS
3730 kg/min
3696 MJ/min
STEAM TO UTILITY
1028 kg/min
2847 MJ/min
HEAT
RECOVERY
MODULE
BOILER FEEDWATER
1226 kg/min
108 MJ/min
STEAM LINE LOSS
32 kg/min
90 MJ/min
ELECTRICITY
9 MJ/min
DEAERATOR VENT
5 kg/min
12 MJ/min
BLOWDOWN
136 kg/min
125 MJ/min
ATOMIZING STEAM
25kg/min
69 MJ/min

Figure 88. Boiler mass and energy balance.

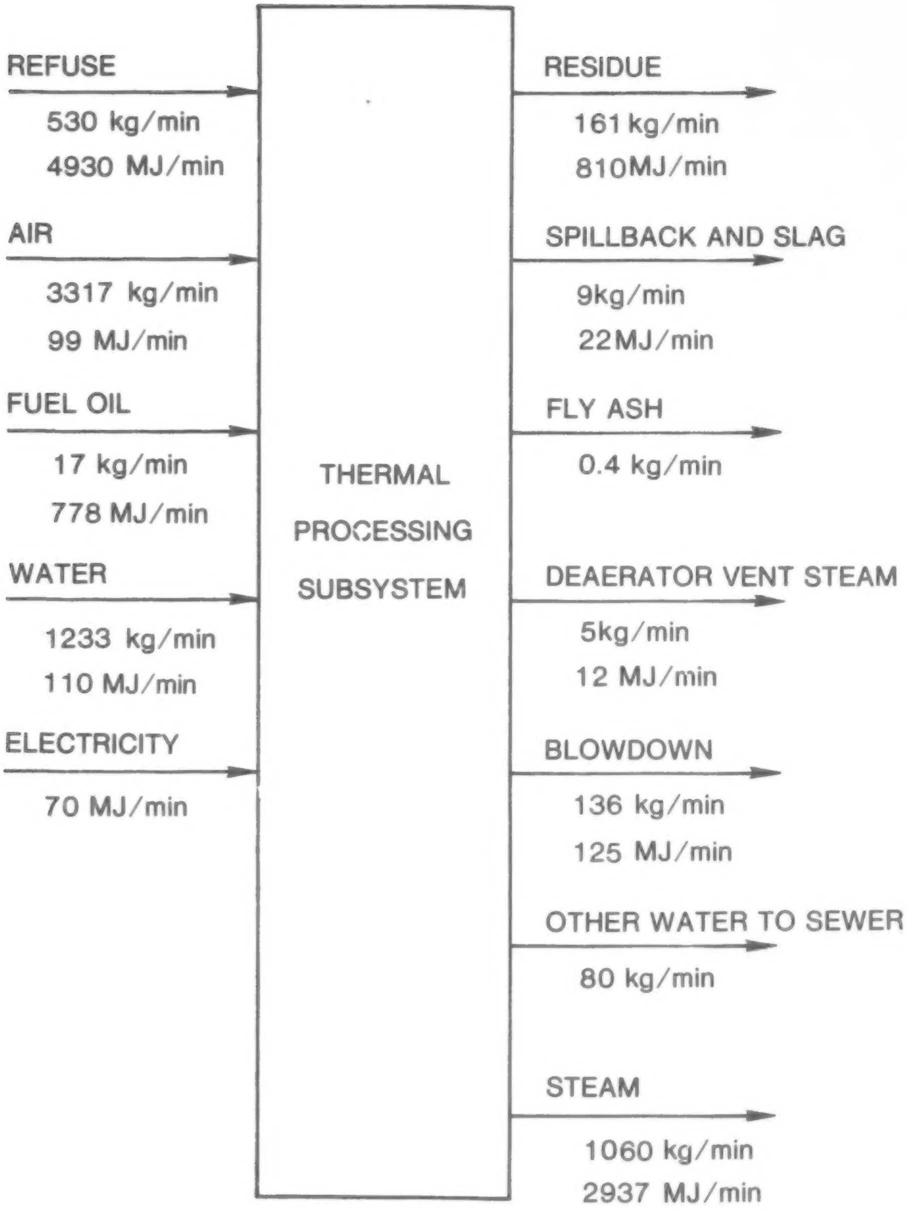

THERMAL PROCESSING SUBSYSTEM
REFUSE
530 kg/min
4930 MJ/min
AIR
3317 kg/min
99 MJ/min
FUEL OIL
17 kg/min
778 MJ/min
WATER
1233 kg/min
110 MJ/min
ELECTRICITY
70 MJ/min
RESIDUE
161 kg/min
810MJ/min
SPILLBACK AND SLAG
9kg/min
22MJ/min
FLY ASH
0.4 kg/min
DEAERATOR VENT STEAM
5kg/min
12 MJ/min
BLOWDOWN
136 kg/min
125 MJ/min
OTHER WATER TO SEWER
80 kg/min
STEAM
1060 kg/min
2937 MJ/min

Figure 89. Thermal processing subsystem mass and energy balance.

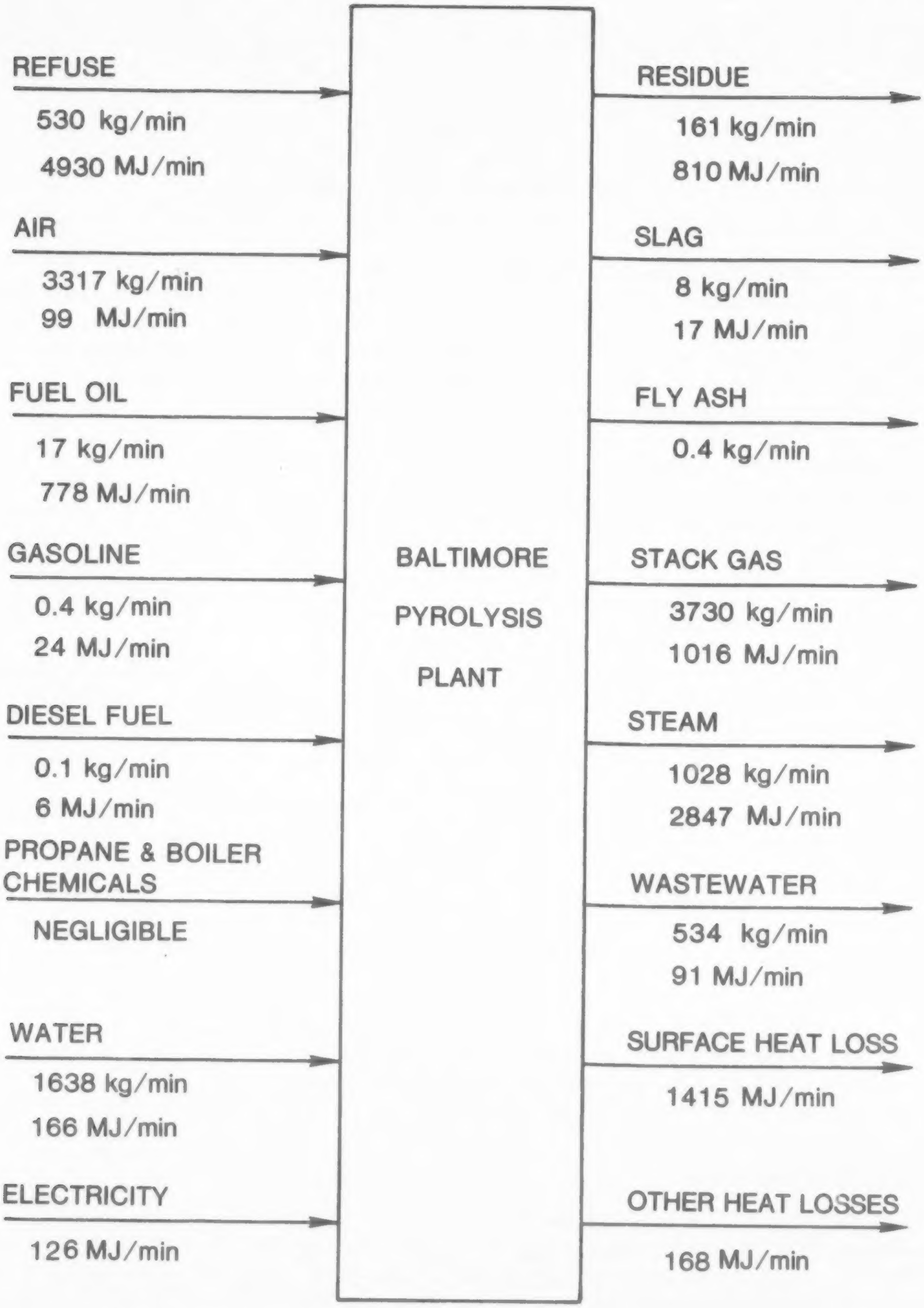

REFUSE
530 kg/min
4930 MJ/min
AIR
3317 kg/min
99 MJ/min
FUEL OIL
17 kg/min
778 MJ/min
GASOLINE
0.4 kg/min
24 MJ/min
DIESEL FUEL
0.1 kg/min
6 MJ/min
PROPANE & BOILER CHEMICALS
NEGLIGIBLE
WATER
1638 kg/min
166 MJ/min
ELECTRICITY
126 MJ/min
BALTIMORE PYROLYSIS PLANT
RESIDUE
161 kg/min
810 MJ/min
SLAG
8 kg/min
17 MJ/min
FLY ASH
0.4 kg/min
STACK GAS
3730 kg/min
1016 MJ/min
STEAM
1028 kg/min
2847 MJ/min
WASTEWATER
534 kg/min
91 MJ/min
SURFACE HEAT LOSS
1415 MJ/min
OTHER HEAT LOSSES
168 MJ/min

Figure 90. Total plant mass and energy balance.

SECTION 4

ENVIRONMENTAL ASSESSMENT

The environmental assessment determines both positive and negative impacts of the facility on the environment. Since the Landgard concept was evolved to solve environmental problems associated with solid waste, the Baltimore plant would be expected to have a positive net environmental impact. Degradation of land and groundwater is reduced by thermally processing solid waste before landfilling. With proper plant design, this positive land impact should not be offset by air or water assaults. As presently configured, however, the Baltimore plant does not live up to these high expectations. The discharge of large amounts of particulate with the combustion products, and the surface discharge of various process wastewaters have a substantial negative impact on air and surface water quality. But fortunately, the completion of certain modifications to the Baltimore plant will enable it to be an environmentally good neighbor and comply with pollution control regulations.

The Landgard concept involves gasification of solid waste with integrated combustion and recovery of the energy potential of the gaseous products to generate steam. The emissions from this plant consist of steam, combustion products with entrained particulate, solid residues, and liquid wastes.

Emissions from the Landgard plant can be considered either from the viewpoint of the pollution receiver (air, water, and land impacts) or the pollution producer (the plant). Because of the complexity of sorting out the air, water, and land impacts, this report will examine the five major types of pollutants produced within the plant--stack emissions, solid residues, plant process waters, fugitive emissions, and noise contamination.

STACK EMISSIONS

The stack at the Baltimore plant is used to direct the discharge of the products of combustion from the process. As a result, the emissions of interest are particulates and gas.

Particulate Emissions

The original design concept presumed that the gas flow through the primary reaction chamber (kiln) was (1) over the solids bed and (2) of low velocity, so that the carryover of particulate would be minimized, much as it is in a starved-air incinerator. After discovering high particulate loadings, the designer theorized the formation mechanism to be as follows: When the atmosphere in the primary chamber (kiln) was maintained at substoichiometric levels, several of the oxidized metals found as coatings on solid waste were reduced to their elemental forms and vaporized. Salts were similarly volatilized. These vapors were then reoxidized and eventually formed a condensation aerosol. As a result of this phenomenon and the carryover of fines from the kiln, the kiln-off-gas particulate loadings were higher than expected.

Though the scrubber performed admirably and in fact exceeded its design specifications for percent particulate removal, the plant could not meet the State of Maryland particulate emission standards of 0.069 g/DSCM (0.03 gr/DSCF).

Monsanto and the City of Baltimore thus tested a portable, single-cell electrostatic precipitator to determine if it could enable the plant to meet the particulate emission requirements of the State. The pilot precipitator was tested on a side stream of the boiler exit gases that had an average inlet particulate loading of 0.6 g/DSCM (0.26 gr/DSCF). This single-cell unit resulted in exit loadings of less than 0.069 g/DSCM (0.03 gr/DSCF).

The plant is presently being upgraded to replace the wet scrubber with electrostatic precipitators to control the particulate emissions. As a result, much of the historical data concerning particulate emissions from the plant are no longer applicable.

To anticipate future emissions compliance before the electrostatic precipitators are actually installed, the combustion products will be examined before they reach the scrubber at the boiler discharge, and the previously conducted portable electrostatic precipitator tests will be used to generate data. The test results shown in Table 72 indicate that the electrostatic precipitators will allow the Baltimore plant to comply with particulate emission standards.

TABLE 72. DRY ELECTROSTATIC PRECIPITATOR TEST OF BOILER EXIT GASES*

Rapping Pressure (kPa)	Velocity (m/s)	Voltage (kv)	Current ($\mu a/m^2$)	Inlet Loading (g/DSCM)	Outlet Loading (g/DSCM)	Efficiency (%)
83	0.67	44	462	0.595	0.030	94.8
110	0.67	49	344	0.538	0.047	91.1
83	0.91	47	355	0.592	0.065	89.2
110	0.91	48	312	0.698	0.049	92.1
69	1.22	50	312	0.549	0.091	83.0
--	----	47	355	3.810†	0.079	97.7

* White, S. J., Jr., Environmental Elements Corporation. Precipitator Application Survey City of Baltimore Pyrolysis Plant. No. 7364. Baltimore, Maryland, 1976. p. VI.

† Blowing soot.

Gaseous Emissions

The scrubber was designed to remove gaseous contaminants as well as particulates. Tables 73 and 74 relate both boiler and scrubber exit gaseous emissions rates and reveal that the scrubber removes approximately 80 percent of the halogens, sulfur dioxide, and short-chain hydrocarbons. Little sulfur trioxide or nitrous oxide, and very few long-chain hydrocarbons are removed by the scrubber.

TABLE 73. BOILER AND SCRUBBER OUTLET GASES

Gas	Boiler Outlet (mg/SCM)		Scrubber Outlet (mg/SCM)		Removal (%)
	Mean	Standard Deviation	Mean	Standard Deviation	
Sulfur dioxide (SO_2)	390.3	89.2	74.8	104.1	81
Nitrogen oxides (NOx)	10.6	12.7	9.0	7.0	15
Sulfur trioxide (SO_3)	36.1	10.1	24.7	10.7	32
Chlorides (Cl-)	713.5	605.4	74.2	80.3	90
Fluorides (F-)	7.7	3.2	1.3	0.5	83

TABLE 74. HYDROCARBON ANALYSIS OF BOILER AND SCRUBBER OUTLET GASES*

Length Of Hydrocarbon Chain	Concentration of n-alkanes		Removal (%)
	Boiler outlet (mg/SCM)	Scrubber outlet (mg/SCM)	
C1	85	13	85
C2	<0.6	<0.6	--
C3	833	234	72
C4	1,634	564	65
C5	<0.6	<0.6	--
C6	682	584	14
C7	1.2	†	--
C8	1.0	†	--
C9-C12	†	†	--

* TRW Environmental Engineering Division. Source Emissions Tests for Industrial Research Labs. EPA 68-01-2988, U.S. Environmental Protection Agency, Cincinnati, Ohio 1977. p.24.

† Not detectable.

The replacement of the scrubber with electrostatic precipitators will solve the particulate emission problem but will increase the gaseous emissions from the boiler because electrostatic precipitators have no effect on gaseous emissions. However, installation of a tall stack will have a beneficial effect. The neutral to negative bouyancy of the combustion products cooled in the dehumidifier often fumigate the immediate downwind area with noxious gases. The stack will disperse these gases so that their concentrations will be lower when they reach ground level.

Gaseous emissions are highly variable. Product gas compositions vary not only with plant load and excess air levels in the primary chamber, but also with the composition of the solid waste feed stream. As a result, it is impossible to determine the exact concentrations of gases emitted from the plant.

As far as criteria pollutants are concerned, no limits presently exist on incinerator emissions of sulfur dioxide or oxides of nitrogen. Sulfur dioxide in the stack gas averages 390 mg/SCM, with a relative standard deviation of 0.25. Nitrogen oxides in the stack gas average 11 mg/SCM, with a relative standard deviation greater than 1. Because of the high variability, it is impossible to say what the absolute emissions are, but the sulfur dioxide and nitrogen oxide emissions are within the legal limits for boilers fired with solid fossil fuels.

The sulfur trioxide (SO_3) emissions from the plant are on the order of 35 mg/SCM, or approximately 10 percent of the sulfur dioxide level. The total hydrocarbons leaving the plant are on the order of 3,240 mg/SCM; they are predominantly C_4 hydrocarbons. The presence of this amount of a large hydrocarbon implies that the gases in the gas purifier are not being properly combusted because of improper mixing and low excess air.

Halogens are also emitted from the plant. Emission rates of 714 mg/SCM for hydrogen chloride and 7 mg/SCM for hydrogen fluoride have been observed. The significance of these emissions cannot yet be assessed, because too few toxicological and epidemiological data exist to determine whether or not these stack concentrations translate to ground level concentrations of concern.

Nevertheless, gaseous emissions from this plant are within or below the range from a solid-fossil-fuel-fired boiler plant, and as a result, they should have no more adverse environmental impact than a coal plant of similar size.

SOLID RESIDUES

In addition to entrained gases and particulates resulting from the gasification of solid waste, other solids are directly emitted from the plant. These are discharged in the form of slag from the gas purifier, primary residue from the kiln discharge, and fly ash from airborn material de-entrained in the waste heat boilers and economizers.

Gas Purifier Slag

Approximately 2 percent of the refuse fed to the Baltimore process reports as slag. This slag comes from solids entrained in the gaseous combustion products from the primary chamber (kiln). The solids are collected as they melt and de-entrain on the walls of the gas purifier. This material is maintained in a molten stage by a constant heat transfer from the radiant fireball in the gas purifier. The slag flows by gravity down the walls of the purifier and through a slag taphole in the bottom. As the slag drips through the taphole, it falls into a water bath, where it is quenched. Rapid chilling of the slag causes the material to fracture and form a relatively fine frit.

The frit has a bulk density of 1700 kg/m^3 and contains 14 percent surface water. The slag is approximately 50 to 60 percent silica, with aluminum the next most significant element (Table 70).

While there are significant quanitites of other metals in the slag, most are in the form of relatively insoluble metal oxides. The most significant heavy metals in the slag are Barium, Lead, Tin, and Zinc (Table 75).

In a leaching test of the slag in water (Table 76), the supernatant was found to have neutral pH, low BOD and COD, total solids of 440 mg/l, and metal levels of 0.5 mg/l or below (except for iron, which had a level of approximately 10 mg/l). As a result, slag can be viewed as inert and should have no adverse impact on the land with proper disposal in a sanitary landfill.

Initial tests of the structural characteristics of the slag indicate that it can be used as a fill or building material. Once a reliable slag source has been created, further work should be done to verify that this material can indeed be used instead of simply occupying space in an approved sanitary landfill.

Kiln Residue

Kiln residue results from the gasification of solid waste in the rotary kiln. While progressing through the kiln, the waste is heated to dry and devolatilize it. A portion of the carbon contained in the remaining solids is then combusted to provide heat for the previous endothermic gasification reactions, and a portion of the fixed carbon char remains. As a result, when the plant is operating properly approximately 44 percent of the refuse fed to the kiln is discharged. If the waste is burned to completion so that no char is present, approximately 33 percent of the refuse is discharged as residue.

The failure to operate the residue separation module has a negative environmental impact. The magnetic metals and glassy aggregate portions of the residue were to be recycled, thus, considerably reducing the amount to be landfilled. The recycling of magnetic metals would also reduce the amount of iron that could be leached from the residue.

TABLE 75. EMISSION SPECTROGRAPHIC SCAN OF SLAG*
(%)

Constituent	Date and Time 6/20/75 0800	 6/21/75 1500
Aluminum	1-10	1-10
Antimony	>0.005	>0.005
Arsenic	>0.005	>0.005
Barium	0.100-1.000	0.100-1.000
Beryllium	>0.001	>0.001
Bismuth	>0.001	>0.001
Boron	0.010-0.100	0.010-0.100
Cadmium	>0.001	>0.001
Calcium	3-30	3-30
Chromium	0.010-0.100	0.010-0.100
Cobalt	0.001-0.010	0.001-0.010
Copper	0.010-0.100	0.010-0.100
Germanium	>0.001	>0.001
Iron	1-10	1-10
Lead	0.100-1.000	0.100-1.000
Magnesium	0.500-5.000	0.500-5.000
Manganese	0.010-0.100	0.010-0.100
Molybdenum	0.001-0.010	0.001-0.010
Nickel	0.001-0.010	0.001-0.010
Phosphorous	0.010-0.100	0.010-0.100
Potassium	0.200-2.000	0.200-2.000
Silicon	3-30	3-30
Silver	0.001-0.010	0.001-0.010
Sodium	2-20	2-20
Strontium	0.010-0.100	0.010-0.100
Thallium	>0.001	>0.001
Tin	0.100-1.000	0.100-1.000
Titanium	0.500-5.000	0.500-5.000
Vanadium	0.001-0.010	0.001-0.010
Zinc	0.100-1.000	0.100-1.000

---

* Herrington, R. C., D. E. Honaker, and B. G. Ward. Baltimore Landgard® Process Characterization. Monsanto Enviro-Chem Systems, Inc. No. 7240. St. Louis, Missouri, 1976. Table 40.

TABLE 76. SLAG LEACHATE ANALYSIS (April 27, 1977)

Item		Amount
pH	(mg/ℓ)	7.3
BOD	(mg/ℓ)	19.0
COD	(mg/ℓ)	31.0
TS	(mg/ℓ)	440.0
VS	(mg/ℓ)	200.0
Cl^-	(mg/ℓ)	49.0
Total coliforms	(MPN/100 mℓ)	<3.0
Cr	(Total mg/ℓ)	<0.05
Pb	(mg/ℓ)	<0.5
Ni	(mg/ℓ)	<0.2
Cu	(mg/ℓ)	<0.05
Zn	(mg/ℓ)	<0.01
Fe	(mg/ℓ)	10.5
Hg	(μg/ℓ)	<0.01

The kiln residue has a bulk density of approximately 1600 kg/m^3 (100 lb/ft^3). Even though the mass reduction is only 56 percent, the volume reduction of the refuse is 96 percent because of the tenfold difference between the bulk density of the refuse and the residue. Volume reduction is important since it affects landfill life.

The moisture content of the kiln residue, which is approximately 30 percent, is higher than that of the slag because of the porous structure of the char. Such a structure greatly increases the effective surface area and traps water. This excess water greatly increases the weight of the residue requiring disposal and becomes a nuisance when it drains out of the truck and onto the road during transportation to the landfill.

Table 77 shows that the proximate and ultimate analyses of residue from the kiln are very similar to those of the residue from an incinerator receiving similar refuse.

The average ash analysis of the kiln residue (Table 68) reveals that silica and iron are the major components of the ash. Though the iron could be leached from a landfill, both of these materials are relatively inert.

The putrescible content of the residue (Table 78) is based on the use of a BOD test. The results reveal that the residue is not totally oxidized and also quantify the portion of the residue that would decompose as a result of biological activity.

TABLE 77. A COMPARISON OF KILN AND INCINERATOR RESIDUES

Constituent	Incinerator* As Received	Incinerator* Dry	Kiln† As Received	Kiln† Dry
Moisture (%)	37.01	--	27.34	--
Ash (%)	57.36	91.04	64.65	87.52
Volatile matter (%)	3.94	6.26	3.88	5.74
Fixed carbon (%)	1.69	2.70	4.20	6.75
Sulfur (%)	--	.22	.11	.16
Heating value (MJ/kg)	--	2.4	2.4	3.9
Carbon (%)	--	7.17	--	6.82
Oxygen (%)	--	2.08	--	1.01
Hydrogen (%)	--	.77	--	.23
Nitrogen (%)	--	.25	--	.37
Chlorine (%)	--	.17	--	--

* City of Baltimore Incinerator #4.

†† Average values.

TABLE 78. RESIDUE PUTRESCIBLE CONTENT

Date	Time	Source	Putrescibles* (%)	COD (%)
9/11/75	0600	Kiln†	0.0113	--
9/11/75	1600	Kiln†	0.0130	--
9/12/75	1600	Kiln†	0.0129	--
9/13/75	1600	Kiln†	0.0115	--
9/14/75	1600	Kiln†	0.0098	--
1/31/77	1500	Kiln	0.04	7.39
3/1/77	--	Kiln	0.1710	18.2
4/28/77	--	Kiln	0.11	12.6
4/28/77	1630	Incinerator§	0.24	4.6

* Based on BOD_5.

† Herrington, R. C., D. E. Honaker, and B. G. Ward. Baltimore Landgard® Process Characterization. Monsanto Enviro-Chem Systems, Inc. No. 7240. St. Louis, Missouri, 1976. Table 38.

§ City of Baltimore Incinerator #4.

Though the composition of the residue varies considerably with different degrees of burnout, the microbial concentration is affected to an even greater degree. If the residue is processed properly, it is effectively sterile as a result of the high temperatures within the kiln, as shown by the first two dates in Table 79. If the kiln residue is underprocessed, the microbial levels are orders of magnitude higher, as shown by the third date in Table 79. The table also reveals that the microbial level in incinerator residue is within the range of microbial levels for similarly processed kiln residue.

TABLE 79. MICROBIAL ANALYSIS OF RESIDUE

Date	Residue source	Standard plate count (organisms/g)	Total coliform (MPN/g)	Fecal streptococci (MPN/g)
2/1/77	Kiln	6,400	---	---
3/1/77	Kiln	8	0	0
4/29/77	Kiln	7.65×10^7	0.2	0.9
4/29/77	Incinerator*	3,200	0	0

* City of Baltimore Incinerator #4.

Leaching tests of kiln and incinerator residue (Table 80) reveal that the supernatant had a neutral pH, low BOD and COD, total solids of approximately 300 mg/l, and metal levels of 0.5 mg/l or below, except for nickel and iron, which had concentrations of less than 3 mg/l. Both of these residues could therefore be viewed as similar and relatively inert. They should have no adverse impact on the land with proper disposal in a sanitary landfill.

Fly Ash

During the recovery of heat from the combustion products leaving the gas purifier, much of the entrained material solidified by the quench air is deentrained as it passes through the tube banks of the boilers and economizers. Approximately 0.09 percent of the refuse fed to the process reports as ash from the bottom of the boilers through a combination of settling in the relatively low-velocity waste heat recovery boiler and impaction onto the boiler tubes. This ash is 30 percent silica and, surprisingly, 15 percent sulfur trioxide (Table 81).

The fly ash tends to contain large quantities of metals (Table 82), a characteristic typical of fly ash from coal-fired boilers. The only heavy metals found in significant amounts in the fly ash, however, are lead and zinc. Since the metals are in the form of relatively insoluble metal oxides, leaching should not be a problem.

TABLE 80. RESIDUE LEACHATE ANALYSIS

Constituent	Kiln	Incinerator* 4/29/77
BOD (mg/l)	28	23
COD (mg/l)	28.9	21.4
Total solids (mg/l)	290	310
Volatile solids (mg/l)	170	120
Chlorides (mg/l)	94	70
Total coliform/100 ml	<3	<3
Cr (mg/l)	<.05	<.05
Pb (mg/l)	<.5	<.5
Ni (mg/l)	.5	1.2
Cu (mg/l)	<.05	<.05
Zn (mg/l)	.05	.18
Fe (mg/l)	2.9	1.2
Hg (μg/l)	<.01	<.01
pH	7.3	7.3

* City of Baltimore Incinerator #4.

TABLE 81. BOILER FLY ASH CHEMISTRY

Constituent	Composition (%) 6/25/76*	 7/20/77
Alumina	13.40	17.61
Chromic oxide	0.10	---
Ferric oxide	7.20	3.67
Lime	12.10	11.18
Manganese dioxide	0.13	---
Magnesia	2.20	3.99
Nickel oxide	<0.01	---
Phosphorus pentoxide	---	2.07
Potassium oxide	4.40	4.08
Silica	34.20	28.42
Sodium oxide	7.80	9.60
Stannic oxide	0.20	---
Sulfur trioxide	---	14.89
Titania	2.40	2.51
Zinc oxide	3.20	---
Undetermined	12.67	1.98

* Herrington, R. C., D. E. Honaker, and B. G. Ward. Baltimore Landgard® Process Characterization. Monsanto Enviro-Chem Systems, Inc. No. 7250. St. Louis, Missouri, 1976. Table 6.

TABLE 82. BOILER FLY ASH ANALYSIS OF AQUA REGIA SOLUBLES*

Element	Percent by Weight
Ag	0.039
Al	4.45
B	0.020
Ba	0.026
Ca	4.46
Cd	0.034
Co	0.0046
Cr	0.028
Cu	0.13
Fe	3.12
Mg	0.84
Mn	0.12
Mo	0.014
Ni	0.019
Pb	1.64
Sb	0.045
Si	0.61
Sn	0.15
Ti	0.92
V	0.043
Zn	1.89

* Unpublished Monsanto Data.

The environmental impact of land disposal of Landgard fly ash is not expected to be significantly worse than that of similar materials from coal-fired boilers.

The fly ash is free of large amounts of carbon and has a size distribution and appearance similar to coal-fired power plant fly ash. This fly ash can possibly be used, therefore, as a construction material in lightweight aggregate building blocks, lightweight concrete, and soil stabilization. This supposition must be verified in the future, however.

PLANT PROCESS WATER

Normally, the only discharge to the sewer consists of sanitary wastewater, boiler blowdown, and feedwater treatment system discharge. All process water in the plant is closed loop and discharges to the sewer only upon emergency draining of the various tanks. The average wastewater flow to the sewer from the Landgard plant is approximately 242 lpm (64 gpm), and ranges from 110 to 1970 lpm (29 to 520 gpm). Of this flow, 28 lpm (7 gpm) is clean water being used for cooling various bearings on fans and other equipment throughout the plant. This water could be reused as makeup water for the various tanks, or it could be added to the recirculating cooling water system. An analysis of wastewater effluent to the sewer is shown in Table 83, which shows that this wastewater has low concentrations of most constituents except dissolved solids.

TABLE 83. AVERAGE ANALYSIS OF VARIOUS PROCESS WATERS

Constituent	Effluent to sewer	Slag quench	Residue quench	Residue truck drainage
pH (mg/ℓ)	---	9.7	10.3	9.7
Alkalinity (mg/ℓ)	81	94	313	670
Acidity (mg/ℓ)	---	---	---	---
BOD_5 (mg/ℓ)	24	16	626	535
COD (mg/ℓ)	81	260	1,583	6,320
Chlorides (mg/ℓ)	247	---	3,207	---
Suspended solids (mg/ℓ)	110	272	495	7,765
Total solids (mg/ℓ)	1,094	782	8,890	11,900
Volatile solids (mg/ℓ)	368	386	4,528	4,560
Volatile suspended solids (mg/ℓ)	36	92	273	1,653
Hardness (mg/ℓ)	227	---	---	---
Sulfide (mg/ℓ)	0.0	---	---	---
Sulfite (mg/ℓ)	0.4	---	---	---
Sulfate (mg/ℓ)	127	---	---	---
Iron (mg/ℓ)	3.4	7.0	401	82
TKN (mg/ℓ)	2.6	1.5	5.3	0.9
Total phosphorous (mg/ℓ)	0.4	1.11	0.47	15.7
Standard plate count (Organism/ml)	69,000	6	37,000	41
Total coliform (MPN/ml)	155	0	0	0
Fecal streptococci (MPN/ml)	184	1	11	105
Lead (mg/ℓ)	0.1	0.35	.75	70
Mercury (mg/ℓ)	.002	0.001	.004	.019

Wastewater is discharged to other than the sanitary sewer only when the kiln seal tank, the residue quench tank, or the scrubber is emptied. The original design called for the discharge from these components to the sewer, but the 7.5-cm (3-in.) drain pipes for these tanks proved to be too small and plugged. To drain the tanks, it was necessary to install gasketed doors that could be opened to allow the process water to flow onto the ground. The emptying of these tanks is practiced infrequently. To remedy this situation, the tanks could be equipped with larger discharge pipes, a back flushing system, or dikes for subsequent collection and disposal to the sanitary sewer. Such alternatives would prevent this wastewater from infiltrating the groundwater beneath the processing area or from flowing to a body of surface water.

As shown in Table 83 the slag quench tank process water has COD and solids concentrations similar to municipal sewage. The low BOD_5 and microorganism levels of the slag quench indicate that this wastewater cannot be treated biologically. This process water has a high pH and heavy metal (iron and lead) concentration than municipal sewage. The pH is not a problem because of the low alkalinity, and the heavy metals are not a problem because this water is discharged to a large sewage system where its small volume permits dilution to safe levels.

The residue quench tank process water has much higher pollutant concentration as compared to the slag quench process water, but it is much more amenable to biological treatment (Table 83). Again, this wastewater can be safely discharged to a sanitary sewer, since this procedure is resorted to only during emergencies and the sewage system is large.

Approximately one-twentieth of the volume of the kiln residue is discharged from the rear tailgate of the dump truck as drainage water. Based on analysis of this discharge (Table 83), this wastewater should not be discharged to the surface but should be collected and sewered, since it does not meet water quality standards. The forthcoming modification of the residue separation building will remedy this situation.

Because of the refuse, residue, slag, and fly ash that cover the ground in the processing area, surface runoff could also cause deterioration of local surface water quality. Though it may not be required by law, sewering the storm runoff from the process area may be advisable.

Except for storm runoff from the nonprocessing areas, all water discharged from the plant should be disposed of in the sanitary sewer. Most of the wastewater will be only slightly purified by biological treatment at a municipal sewage treatment plant. The high concentrations of heavy metals in some of the process waters could have a bactericidal effect at the sewage treatment plant if the wastewater is not sufficiently diluted. But since the stronger process waters are discharged very infrequently and the volume is small, the effect on the final effluent from the sewage treatment plant should be minimal.

FUGITIVE EMISSIONS

Fugitive emissions in the work place include dust, microorganisms, and gases that might have adverse health effects.

Dust loadings in the Baltimore plant range from 0.009 to 0.025 g/m^3 (Table 84). They are highest in the receiving area, where the waste is being discharged from packer trucks. This dust is biologically active, with the standard plate counts in the range of 111,000 counts/g (Table 85)--comparable

TABLE 84. DUST LEVELS

Date	Location	Loading (g/m^3)
5/ 3/77	Receiving building	0.025
5/ 3/77	Rams	0.0092
5/ 4/77	Transfer tower	0.0198
5/ 5/77	A3 Shredder	0.0146
5/ 5/77	Transfer tower	0.0167
5/ 9/77	Z9-Z10 Transfer	0.0094
5/11/77	Atlas	0.0104

TABLE 85. MICROBIAL LEVELS IN REFUSE DUST

Organism	Concentration
Standard plate count (counts/g)	111,000
Bacteria* (counts/g)	27,000 - 730,000,000
Salmonella*	Present
Fecal coliform* (MPN/g)	1,400 - 512,000
Fecal coliform* (MPN/g)	2,400
Fecal streptococci (MPN/g)	2,400
Staphylococcus aureus (MPN/g)	460
Enterovirus (PFU/g)*	735 - 171,232
Bacteriophage (PFU/g)*	27,000 - 900,000

* St. Louis Demonstration Final Report: Refuse Processing Plant Equipment, Facilities, and Environmental Evaluation, 1976. D. E. Fiscus, ed. Midwest Research Institute, Kansas City, Missouri. Tables 26 and 27, pp. 113-114.

to the levels found at the Union Electric resource recovery facility in St. Louis. The dust levels throughout the Baltimore plant are sufficient to produce a 2.5 cm (1 in.) dust layer over most of the operating equipment within a week. This nuisance can be improved upon by proper air handling and dust collecting equipment.

The significance of biological activity in samples of work-place dust collected in Baltimore is totally unknown and beyond the scope of this report.

Significant epidemiological work must therefore be performed to determine whether or not the handling of solid waste poses an environmental hazard for the worker. Some of the plant personnel have developed skin irritations that they associate with the plant dust.

Carbon monoxide is a workplace hazard because it causes insidious toxicity and possible death. The threshold limit value (TLV) for carbon monoxide is 50 μl/l. Throughout the monitoring of the Baltimore plant, peak carbon monoxide levels of 100 to 190 μl/l were observed at the edge of the tipping floor when more than two trucks were present (Table 86). In the refuse pit, levels of 35 μl/l were observed, whereas levels on the tipping floor ranged from 34 to 70 μl/l. These carbon monoxide levels could probably be substantially improved by installing fans in the roof ventilators of the receiving building.

At present, only the laborer who directs the refuse trucks to the various tipping bays is exposed to carbon monoxide in the tipping floor area 8 hr/day. Though the peak limits greatly exceed the TLV, this worker is usually away from the trucks and in an area where the levels are much lower. The periodic nature of the truck dumping also limits his exposure.

The dozer operator is exposed to carbon monoxide in the storage pit air for 8 hour per day, but the level there is less than the TLV.

Refuse truck drivers and laborers are exposed to the highest levels of carbon monoxide, but only for short periods of time. No significant concentrations of carbon monoxide were found elsewhere in the plant. It can, therefore, be concluded that carbon monoxide poses no work hazard in this facility.

NOISE

For an 8-hour exposure, noise levels must be kept below 90 dBA to comply with OSHA regulations. The noise level throughout the majority of the Baltimore plant was less than 90 dBA (Figures 91 through 96). The general plant area was usually in the range of 80 to 90 dBA. Noise levels ranged upward of 120 dBA in the vicinity of the retractable soot blowers, and they registered about 90 dBA near the rotary soot blowers (Table 87). The high noise from the soot blowers is of an intermittent nature, and workers in the immediate environment use ear plugs or headsets while operating this equipment.

TABLE 86. ANALYSIS OF RECEIVING BUILDING AIR

Date	Time	Test	Location	Concentration (μl/ℓ)	Comments
6/25/76†	0955	H_2S	North side	<1.0	3 Trucks & 1 Dozer
6/25/76†	0958	C_2H_3CL	North side	1.0	3 Trucks & 1 Dozer
6/25/76†	1003	SO_2	North side	*	3 Trucks & 1 Dozer
6/25/76†	1006	NH_3	North side	*	3 Trucks & 1 Dozer
6/25/76†	1008	Cl_2	North side	< .5	3 Trucks & 1 Dozer
6/25/76†	1015	NO	North side	2.0	3 Trucks & 1 Dozer
6/25/76†	1015	NO_2	North side	<1.0	3 Trucks & 1 Dozer
6/25/76†	0945	CO	Northeast corner	50	3 Trucks & 1 Dozer
6/25/76†	0950	CO	Northeast corner	50	3 Trucks & 1 Dozer
6/25/76†	1020	CO	Southeast corner	50	1 Dozer
6/25/76†	1022	CO	Southeast corner	>50	1 Dozer
6/25/76†	1030	CO	Dozer cab	>25	
6/25/76†	1040	CO	Dozer cab	40	
6/25/76†	1045	CO	Dozer cab	40	
6/25/76†	1050	CO	Dozer cab	40	
4/27/77†	1300	CO	Northwest corner	23	1 Dozer
4/27/77	1300	CO	West central side	4	1 Dozer
4/27/77	1300	CO	Southwest corner	5	1 Dozer
4/27/77	1300	CO	Northeast corner	22	1 Dozer
4/27/77	1300	CO	East central side	15	1 Dozer
4/27/77	1300	CO	Southeast corner	20	1 Dozer
4/27/77	1300	CO	North storage pit	16	1 Dozer
4/27/77	1300	CO	South storage pit	16	1 Dozer
4/27/77	1300	CO	Central storage pit	3	1 Dozer
4/28/77	1015	CO	Northwest corner	41	2 Trucks
4/28/77	1015	CO	West central side	38	2 Trucks
4/28/77	1015	CO	Southwest corner	50	2 Trucks
4/28/77	1015	CO	Northeast corner	10	2 Trucks
4/28/77	1015	CO	East central side	56	2 Trucks
4/28/77	1015	CO	Southeast side	68	2 Trucks
4/28/77	1015	CO	North storage pit	31	2 Trucks
4/28/77	1015	CO	South storage pit	58	2 Trucks
4/28/77	1020	CO	East central side	98	1 Truck & 2 Dozers
4/28/77	1025	CO	East central side	130	2 Trucks & 2 Dozers
5/03/77	0930	CO	Northwest corner	70	2 Trucks & 2 Dozers
5/03/77	0930	CO	West central corner	36	2 Trucks & 2 Dozers
5/03/77	0930	CO	Southwest corner	34	2 Trucks & 2 Dozers
5/03/77	0930	CO	Northeast corner	150	5 Trucks & 1 Dozer
5/03/77	0930	CO	East central corner	190	5 Trucks & 1 Dozer
5/03/77	0930	CO	Southeast corner	170	4 Trucks & 1 Dozer
5/03/77	0930	CO	North storage pit	160	4 Trucks & 1 Dozer
5/03/77	0930	CO	South storage pit	160	3 Trucks & 1 Dozer
5/03/77	0930	CO	Central storage pit	35	1 Truck & 2 Dozers

* None detected.

† Herrington, R. C., D. E. Honaker, and B. G. Ward. Baltimore Landgard® Process Characterization. Monsanto Enviro-Chem Systems, Inc. No. 7250 St. Louis, Missouri, 1976. Table 10.

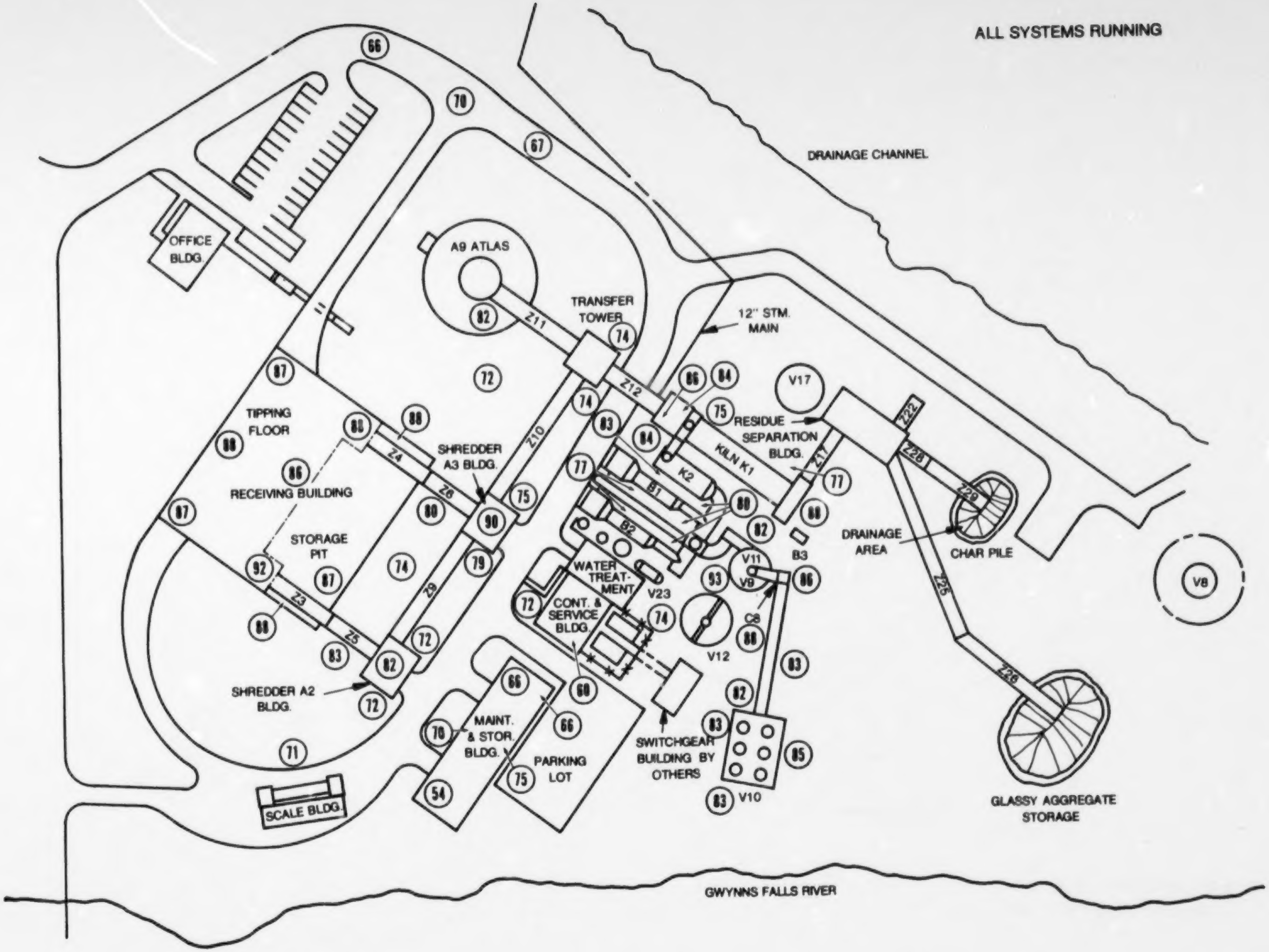

ALL SYSTEMS RUNNING
DRAINAGE CHANNEL
66
70
67
OFFICE BLDG.
A9 ATLAS
82
Z11
TRANSFER TOWER
74
12" STM. MAIN
72
87
TIPPING FLOOR
88
86
88
86
RECEIVING BUILDING
87
Z4
Z6
SHREDDER A3 BLDG.
80
90
75
Z10
74
STORAGE PIT
92
87
74
79
Z9
Z3
88
Z5
83
82
72
SHREDDER A2 BLDG.
72
71
SCALE BLDG.
Z12
86
84
75
83
84
77
B1
K2
KILN K1
B2
80
RESIDUE SEPARATION BLDG.
V17
Z17
77
68
82
B3
Z22
Z28
Z29
DRAINAGE AREA
CHAR PILE
V8
Z25
Z26
GLASSY AGGREGATE STORAGE
WATER TREATMENT
V23
72
CONT. & SERVICE BLDG.
74
93
V11
V9
86
C8
88
V12
83
82
83
85
83
V10
60
66
66
MAINT. & STOR. BLDG.
70
75
PARKING LOT
54
SWITCHGEAR BUILDING BY OTHERS
GWYNNS FALLS RIVER

Figure 91. Noise survey (dBA are circled). Date and time: 2/25/77, 0900.

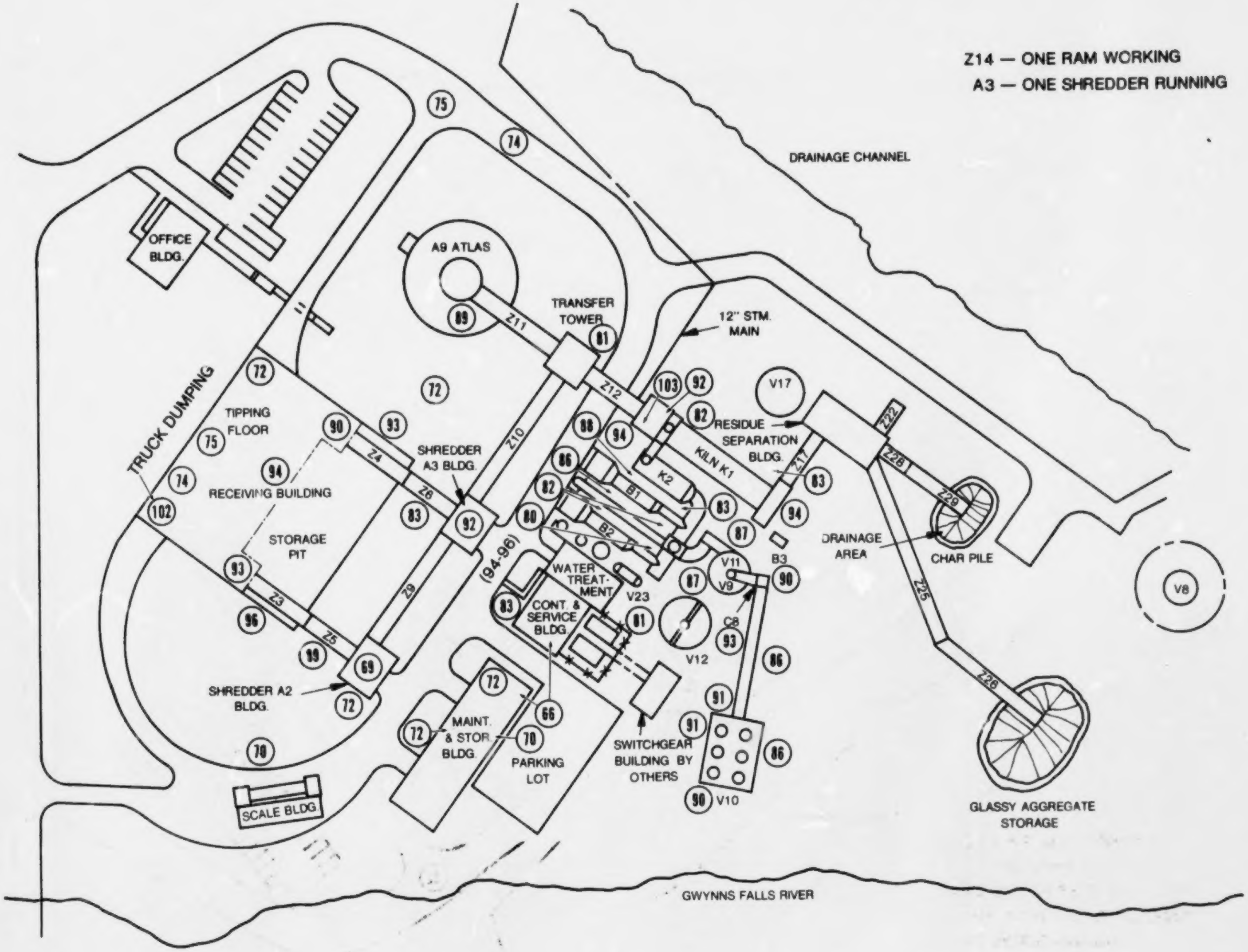
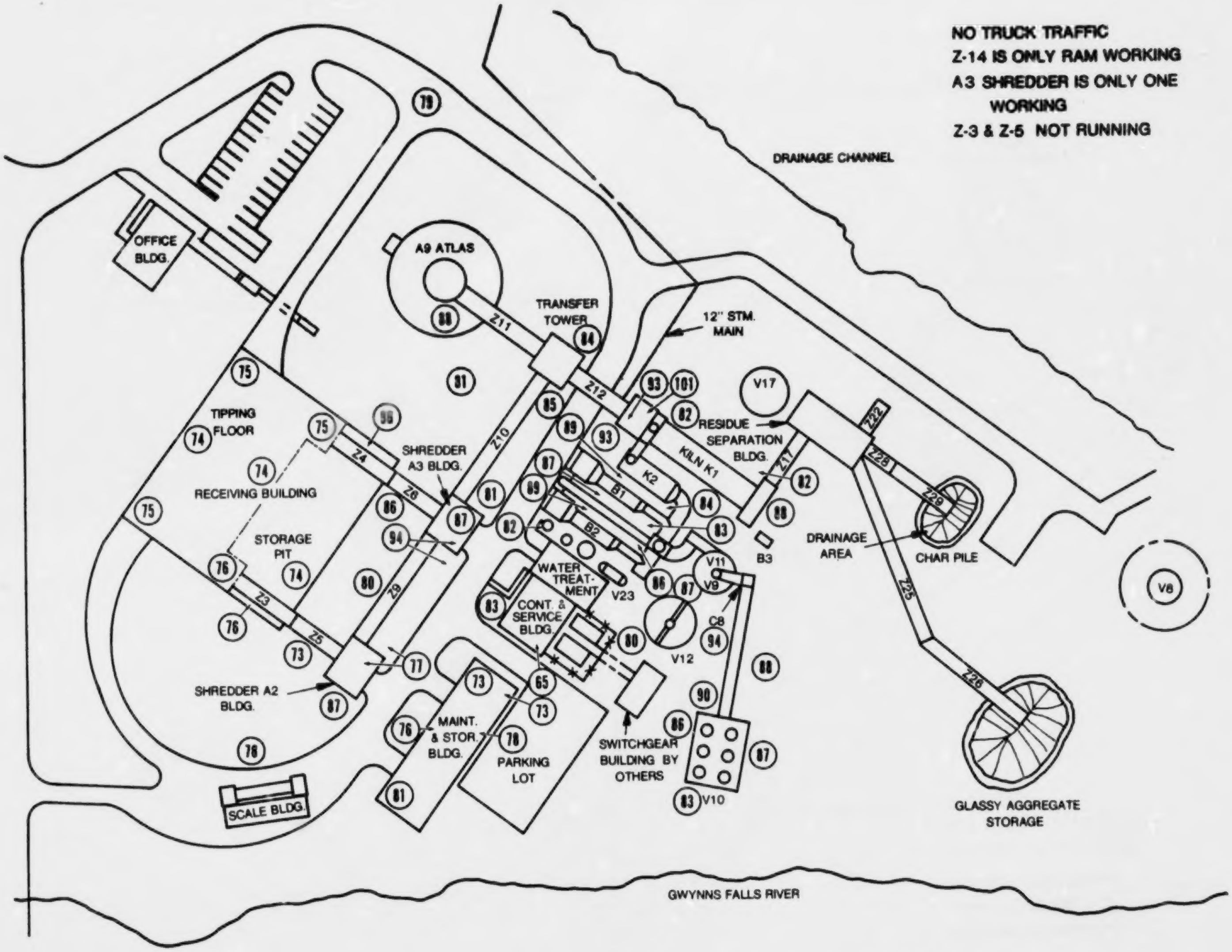

Z14 — ONE RAM WORKING
A3 — ONE SHREDDER RUNNING
DRAINAGE CHANNEL
OFFICE BLDG.
A9 ATLAS
TRANSFER TOWER
12" STM. MAIN
V17
RESIDUE SEPARATION BLDG.
KILN K1
K2
B1
B2
B3
Z22
Z28
Z29
Z25
Z26
Z17
Z12
Z11
Z10
Z9
Z6
Z4
Z3
Z5
DRAINAGE AREA
CHAR PILE
V8
V11
V9
C8
V12
V23
V10
WATER TREAT-MENT
CONT. & SERVICE BLDG.
SWITCHGEAR BUILDING BY OTHERS
GLASSY AGGREGATE STORAGE
TRUCK DUMPING
TIPPING FLOOR
RECEIVING BUILDING
STORAGE PIT
SHREDDER A3 BLDG.
SHREDDER A2 BLDG.
MAINT. & STOR. BLDG.
PARKING LOT
SCALE BLDG
GWYNNS FALLS RIVER
(94-96)
75
74
89
81
72
103
92
82
88
94
86
83
94
87
90
80
87
93
91
86
91
86
90
72
93
90
75
74
94
102
83
92
93
96
99
69
72
70
72
66
72
70
81

Figure 92. Noise survey (dBA are circled). Date and time:3/10/77, 0830.


DRAINAGE CHANNEL
OFFICE BLDG.
79
A9 ATLAS
88
Z11
TRANSFER TOWER
84
12" STM. MAIN
81
Z12
93
101
V17
82
RESIDUE SEPARATION BLDG.
KILN K1
K2
B1
B2
Z22
Z28
Z29
Z17
82
88
B3
DRAINAGE AREA
CHAR PILE
Z25
Z26
V8
GLASSY AGGREGATE STORAGE
75
TIPPING FLOOR
74
75
96
Z4
SHREDDER A3 BLDG.
74
RECEIVING BUILDING
75
Z8
85
89
93
87
89
Z10
81
87
82
84
83
86
94
STORAGE PIT
76
74
80
Z9
Z3
76
73
Z5
77
SHREDDER A2 BLDG.
87
78
SCALE BLDG.
WATER TREAT-MENT
V23
83
CONT. & SERVICE BLDG.
80
V11
V9
86
87
C8
94
V12
88
65
73
73
76
MAINT. & STOR. BLDG.
78
PARKING LOT
81
SWITCHGEAR BUILDING BY OTHERS
90
86
87
83
V10
GWYNNS FALLS RIVER

NO TRUCK TRAFFIC
Z-14 IS ONLY RAM WORKING
A3 SHREDDER IS ONLY ONE WORKING
Z-3 & Z-5 NOT RUNNING

Figure 93. Noise survey (dBA are circled). Date and time: 3/17/77, 1600.

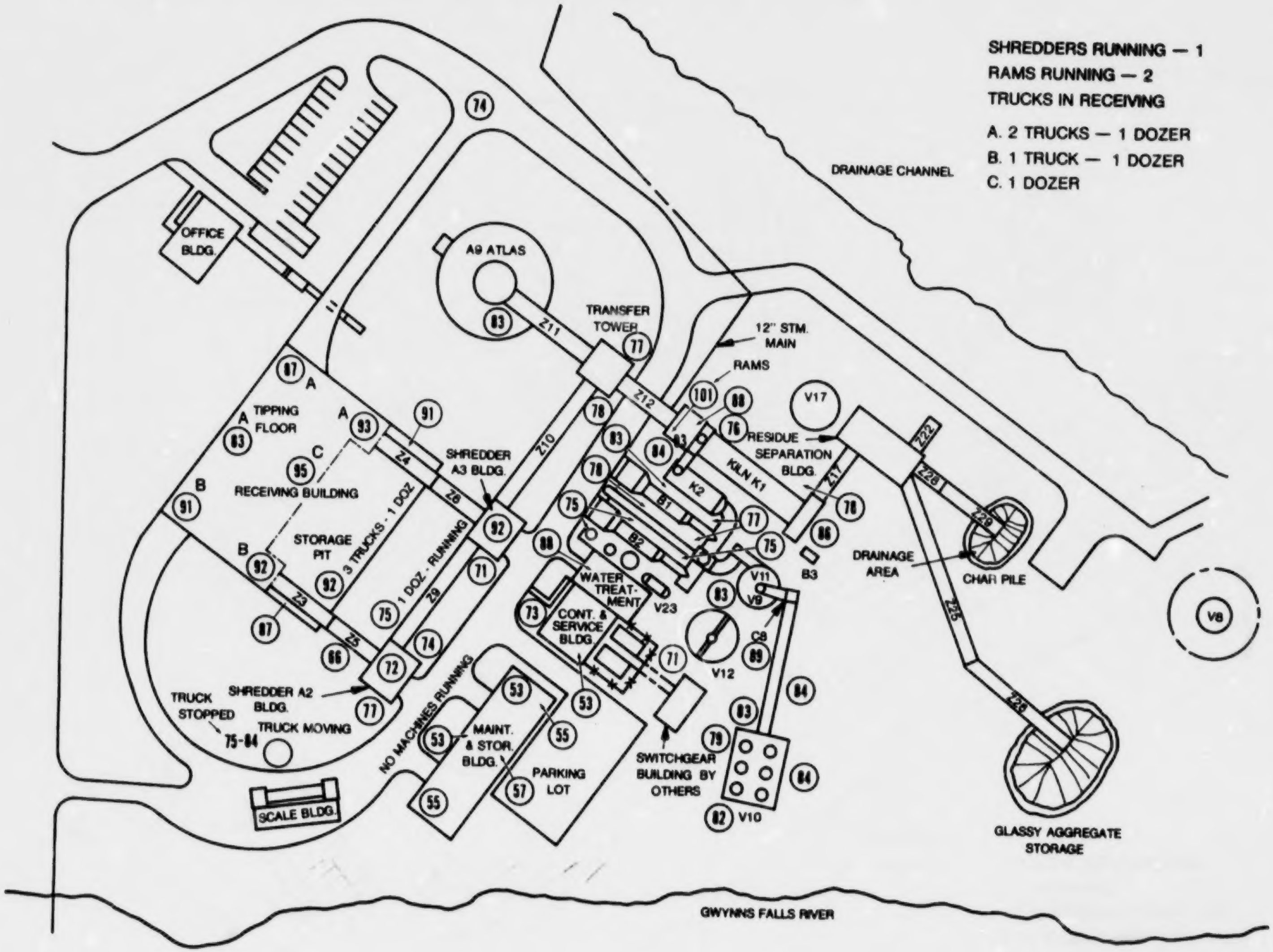

SHREDDERS RUNNING — 1
RAMS RUNNING — 2
TRUCKS IN RECEIVING
A. 2 TRUCKS — 1 DOZER
B. 1 TRUCK — 1 DOZER
C. 1 DOZER
DRAINAGE CHANNEL
GWYNNS FALLS RIVER
OFFICE BLDG.
A9 ATLAS
TRANSFER TOWER
12" STM. MAIN
RAMS
V17
RESIDUE SEPARATION BLDG.
KILN K1
K2
B1
B2
B3
Z10
Z11
Z12
Z17
Z22
Z23
Z24
Z25
Z26
Z28
Z29
Z9
TIPPING FLOOR
RECEIVING BUILDING
STORAGE PIT
3 TRUCKS - 1 DOZ
1 DOZ. - RUNNING
SHREDDER A3 BLDG.
SHREDDER A2 BLDG.
TRUCK STOPPED
TRUCK MOVING
75-84
SCALE BLDG.
NO MACHINES RUNNING
WATER TREAT-MENT
V23
CONT. & SERVICE BLDG.
MAINT. & STOR. BLDG.
PARKING LOT
SWITCHGEAR BUILDING BY OTHERS
V9
V10
V11
V12
C8
V8
DRAINAGE AREA
CHAR PILE
GLASSY AGGREGATE STORAGE
74
83
77
78
101
88
76
84
83
78
75
77
75
86
78
88
83
89
84
83
79
84
82
73
53
71
53
55
53
57
55
87
83
93
91
95
91
92
92
92
71
75
74
87
66
72
77

Figure 94. Noise survey (dBA are circled). Date and time: 4/28/77, 1000.

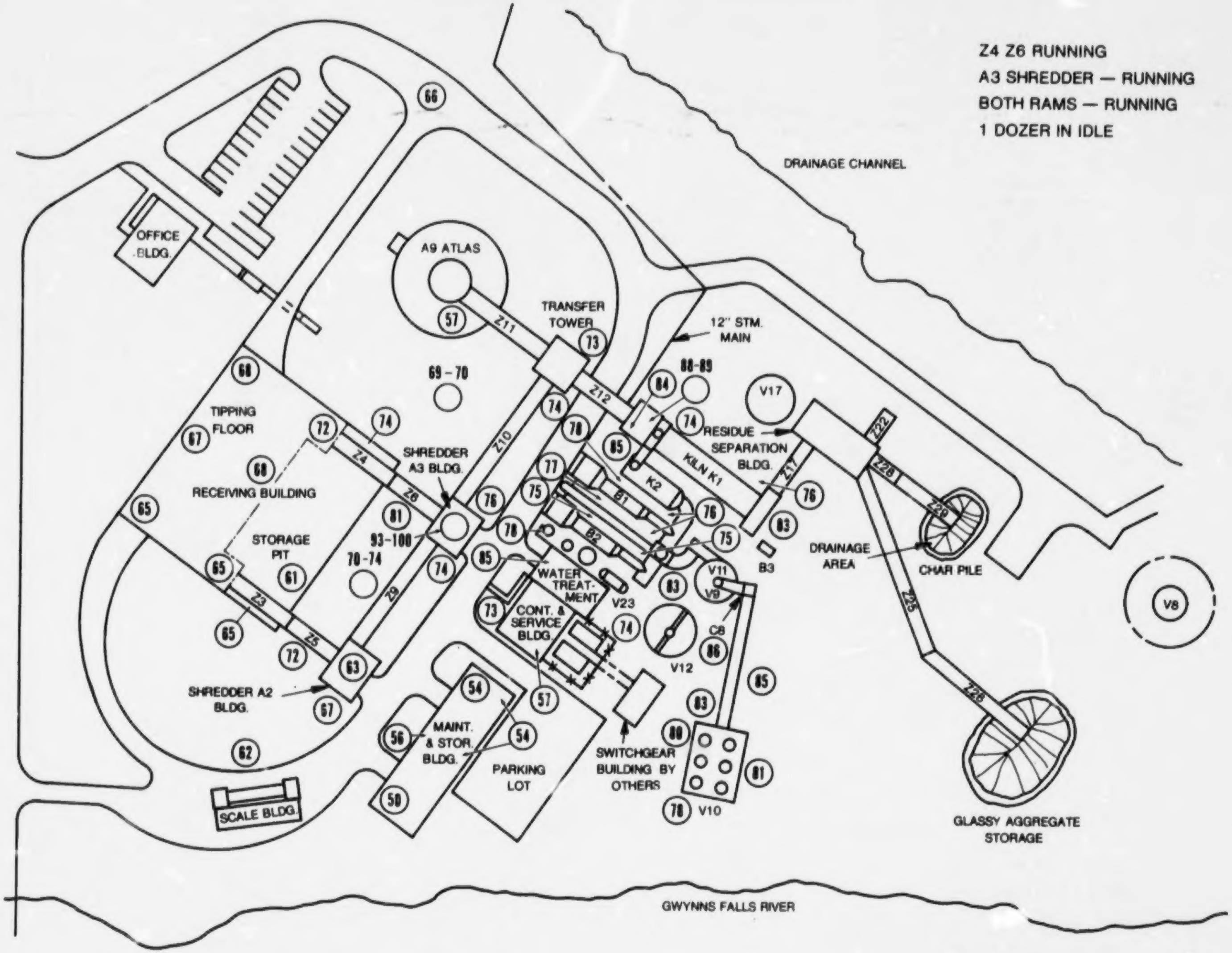

Z4 Z6 RUNNING
A3 SHREDDER — RUNNING
BOTH RAMS — RUNNING
1 DOZER IN IDLE
DRAINAGE CHANNEL
OFFICE BLDG.
66
A9 ATLAS
57
Z11
TRANSFER TOWER
73
12" STM. MAIN
88-89
84
V17
74
RESIDUE SEPARATION BLDG.
Z22
Z28
Z26
Z17
KILN K1
K2
B1
B2
B3
76
83
DRAINAGE AREA
CHAR PILE
Z25
V8
69 – 70
68
TIPPING FLOOR
67
72
74
Z4
SHREDDER A3 BLDG.
Z6
68
RECEIVING BUILDING
65
81
93-100
70-74
STORAGE PIT
61
Z9
Z10
74
78
85
77
75
76
78
76
75
85
WATER TREATMENT
V23
83
V11
V9
C8
86
V12
65
Z3
65
72
Z5
63
73
CONT. & SERVICE BLDG.
74
57
SHREDDER A2 BLDG.
67
54
56
MAINT. & STOR. BLDG.
54
PARKING LOT
50
62
SCALE BLDG.
SWITCHGEAR BUILDING BY OTHERS
85
83
88
81
78
V10
GLASSY AGGREGATE STORAGE
GWYNNS FALLS RIVER

Figure 95. Noise survey (dBA are circled). Date and time: 5/5/77, 1700.

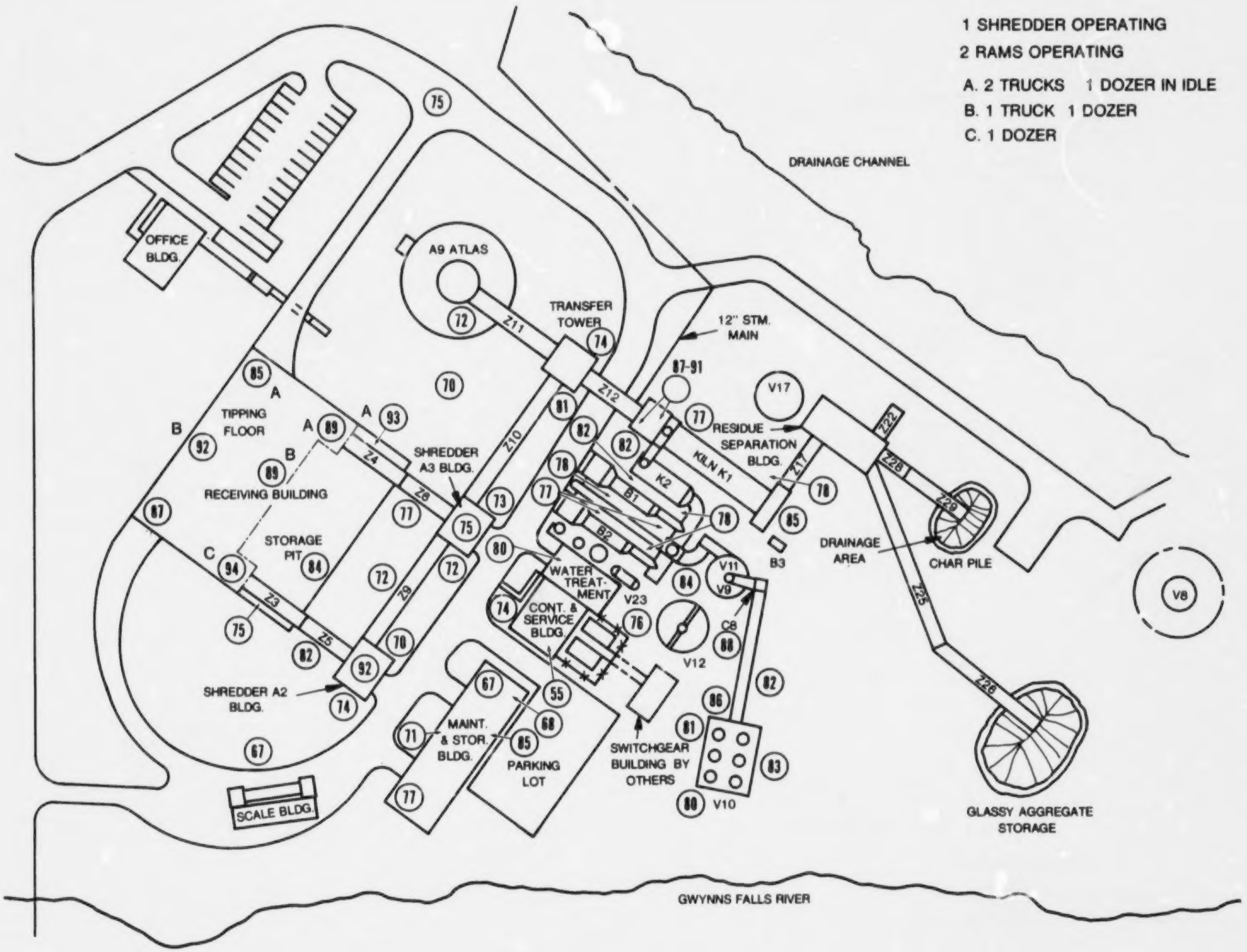

1 SHREDDER OPERATING
2 RAMS OPERATING
A. 2 TRUCKS 1 DOZER IN IDLE
B. 1 TRUCK 1 DOZER
C. 1 DOZER
DRAINAGE CHANNEL
75
OFFICE BLDG.
A9 ATLAS
72
Z11
TRANSFER TOWER
74
12" STM. MAIN
87-91
V17
77
RESIDUE SEPARATION BLDG.
Z22
Z28
Z29
85
A
TIPPING FLOOR
B
92
A
89
A
93
70
81
Z12
82
82
KILN K1
K2
Z17
78
B
89
Z4
B1
RECEIVING BUILDING
Z8
SHREDDER A3 BLDG.
Z10
78
77
87
77
73
78
85
DRAINAGE AREA
CHAR PILE
STORAGE PIT
75
B2
80
B3
C
94
84
72
72
WATER TREATMENT
V11
V9
84
V8
Z9
V23
Z3
74
CONT. & SERVICE BLDG.
76
C8
Z25
75
82
Z5
70
88
V12
92
82
SHREDDER A2 BLDG.
74
67
55
86
Z26
71
MAINT. & STOR. BLDG.
68
81
85
PARKING LOT
SWITCHGEAR BUILDING BY OTHERS
83
67
77
80
V10
GLASSY AGGREGATE STORAGE
SCALE BLDG.
GWYNNS FALLS RIVER

Figure 96. Noise survey (dBA are circled). Date and time: 5/13/77, 0930.

TABLE 87. NOISE LEVELS DURING SOOT BLOWING

Soot blower No.	Soot blower type	Noise level (dBA)
1	Retractable	110
2	Retractable	117
3	Retractable	114
4	Retractable	120*
5	Rotary	90
6	Rotary	94
7	Rotary	94
8	Rotary	90
9	Retractable	120
10	Retractable	110
11	Retractable	105
12	Retractable	105

* Pulses up to 130.

A noise level above 90 dBA also exists near the induced-draft fan. In this area, noise is reflected from the fan as well as from the various tanks within the immediate vicinity, and the cumulative impact exceeds 90 dBA.

The one point of high noise level near the C8 fan is a low-access area in which workers need not work for 8 hours. Any employees stationed there for a repair task while the process is on line are equipped with ear plugs and protected from the potential hazard. Consequently, noise is not considered to be a major problem at the Baltimore Landgard facility.

SECTION 5

ECONOMIC EVALUATION*

BACKGROUND AND PURPOSE

This section presents the costs associated with construction and operation of the Baltimore Landgard system as well as cost projections on various plant operating and system characteristics. This analysis is in accord with the EPA's Accounting Format,† but it does not necessarily conform to Generally Accepted Accounting Principles (GAAP). A discussion of how the Accounting Format deviates from GAAP is presented in Appendix C.

The EPA Accounting Format was developed to facilitate economic comparisons of resource recovery systems. It consists of two formats that are designed to reflect actual and normalized resource recovery system costs and revenues. The actual accounting format is designed to reflect costs and revenues of a recovery system incorporating site-specific parameters. The normalized accounting format removes the site-specific aspects of parameters affecting plant costs (cost of land and labor rates for example) and otherwise compensates for varying local conditions. The normalized format thus permits comparisons with other systems.

Each of the two formats contains three components--capital costs, operating and maintenance costs, and revenues. Capital costs are categorized as those for land, site preparation, design, construction, real equipment, other equipment, contingencies, start-up and working capital, and finance and legal services. Operating and maintenance costs are broken down into expenditures for salaries, employee benefits, fuel, electricity, water and sewer, maintenance, replacement equipment, residue removal, other overhead, taxes and licenses, insurance, management fees, and professional services. Revenues are categorized by recovered materials sold. Definitions of the above categories may be found in EPA's Accounting Format.

---

* The economic analysis presented in the section was prepared and documented by Arthur Young & Company.

† U.S. Environmental Protection Agency. Accounting Format. SW-157.6, 1976.

When costs and revenues are calculated according to the above formats, the following items can be determined:

- Average annual capital costs
- Capital cost per throughput ton
- Total annual operating and maintenance costs
- Operating and maintenance costs per ton
- Total revenues per throughput ton
- Net operating cost/profit

In addition, capital and operating and maintenance costs are allocated to seven cost centers to facilitate translation of the Baltimore experience to other plant designs. The cost centers correspond to the major subsystems within the plant: Receiving, size reduction, storage and recovery, thermal processing, energy recovery, residue separation, and general plant.

Because of the erratic operating status of the plant, the continuing equipment modifications, and the methods by which the City of Baltimore records Landgard operating costs, the economic evaluation was somewhat modified. Three operating scenarios were derived by SYSTECH and utilized by Arthur Young & Company to support the cost calculations and presentation (Table 88). These scenarios were developed to account for the inoperation of various subsystems (i.e., the residue separation and gas scrubber system) and for proposed plant improvements (i.e., the electrostatic precipitator). In addition, the scenarios compensate for the limited and erratic operating status of the plant by providing projected costs and revenues based on varying degrees of plant availability. Thus the costs accumulated under the accounting formats depict projected as opposed to actual costs and revenues.

The method by which the City of Baltimore records Landgard operating costs is inadequate for evaluation purposes because it employs a modified accrual basis of accounting. Under this method, revenues are not recorded when earned, but rather as received; expenses on the other hand, tend to be recorded when incurred, regardless of when they are paid. This recording method does not provide for the proper matching of revenues and expenses. For example, this system does not require accounting for inventories such as fuel oil. Purchases of fuel oil thus charged to expense as purchases and do not really reflect fuel consumption costs for a given period. To achieve a proper matching of revenue and expense, fuel purchases would have to be established in an inventory and charged to expense when actually used.

The three scenarios are primarily distinguished by their varied operating statuses. The first scenario's operating status corresponds to the plant's performance from November 1976 to July 1977, and is characterized by frequent plant shutdowns. The second scenario's operating status is based on an expanded operating staff and more efficient administrative procedures. These changes in plant operation are estimated to increase the average continuous plant operating period more than twofold. The third scenario's operating status is based on the most optimistic operating conditions possible and on equipment improvements that are presently being initiated. As a result, this

TABLE 88. SCENARIO OPERATING PARAMETERS*

	Scenario 1:	Scenario 2:	Scenario 3
Operating schedule:	24 hr/day, 6 days/week, 24 shutdowns/yr	24 hr/day, 7 days/week, 8 shutdowns/yr	24 hr/day, 7 days/week, 4 shutdowns/yr
Operating status (days):			
Normal processing, †	104	264	312
Standby, §	56	21	18
Heating and cooling, ¶	48	16	8
Downtime, **	157	64	27
Refuse feed rate:			
Mg/hr	27	32	36
Mg/yr	67,000	203,000	270,000
Steam production (kg/hr):			
Normal processing	50,000 (2/3)	59,000 (2/3)	66,000
	35,000 (1/3)	35,000 (1/3)	---
Standby	35,000	35,000	35,000
Staffing:			
Plant manager	1	1	1
Plant supervisor	1	1	1
Clerk typist	1	1	1
Chief operators	5	4	4
Field operators	5	12	8
Ram operators	3	--	--
Equipment operators	3	4	4
Laborers	5	7	5
Scalemen	1	1	1
Engineers	--	1	1
Laborers/chauffeurs	7	5	4
Maintenance supervisor	1	1	1
Electricians	2	2	1
Mechanics	3	6	4
Welders	2	1	1
Oilers	--	1	1
Instrument technicians	--	1	1
Total staffing	40	49	39
Fuel consumption (ℓ/hr):			
No. 2 fuel:			
Normal processing	660	660	660
Standby	3,260	3,260	3,260
Heating and cooling	1,960	1,960	1,960
Downtime	0	0	0

CONTINUED

TABLE 88. CONTINUED

	Scenario 1:	Scenario 2:	Scenario 3:
Gasoline:			
Normal processing	620	620	620
Standby	620	620	620
Heating and cooling	93	93	93
Downtime	93	93	93
Diesel fuel:			
Normal processing	208	208	208
Standby	208	208	208
Heating and cooling	64	64	64
Downtime	64	64	64
Electricity consumption (kw):			
Normal processing	2,100	2,100	2,100
Standby	1.109	1.109	1,109
Heating and cooling	1,109	1,109	1,109
Downtime	142	142	142
Water consumption (ℓ/day):			
Normal processing	1,595,380	1,835,140	2,021,620
Standby, ††	1,195,780	1,195,780	1,195,780
Heating and cooling	187,780	187,780	187,780
Downtime	187,780	187,780	187,780
Sewer flow (ℓ/day):			
Normal processing	395,380	419,140	437,620
Standby	355,780	355,780	355,780
Heating and cooling	187,780	187,780	187,780
Downtime	187,780	187,780	187,780

* Provided by SYSTECH.

† Constitutes processing of waste.

§ Constitutes onstream with no processing of waste.

¶ Involves startup and cool-down of kiln.

** No activity, plant shut down.

†† 35 Mg/hr of steam.

scenario represents the longest continuous plant operating period. The manner in which scenario operating parameters were derived is further explained in the discussion of operating and maintenance costs.

Operating status is not the only major difference in scenario parameters. Others include variation in refuse feed rate, steam production, and staffing. Refuse feed rate estimates were based on City and SYSTECH data, and they range from the average (Scenario 1) to the maximum (Scenario 3) recorded refuse shredding rate. Steam production estimates were also based on City and SYSTECH data, but for Scenario 3, it was also assumed that the market could absorb all steam produced from the Landgard system throughout the year. Staffing estimates for Scenarios 2 and 3 were based on engineering judgments, whereas actual plant staffing is used for Scenario 1.

OPERATING AND MAINTENANCE COSTS

Because of the discontinuous plant operations and the lack of compatibility between City accounting records and EPA guidelines, the initial step of auditing and gathering historical operating and maintenance cost information was not possible. As an alternative, operating and maintenance costs were projected utilizing engineering and operating judgment provided by SYSTECH.

Parameters and data were provided for three separate sets of operating conditions. All costs that are ultimately reflected in the EPA classification categories are based on the scenario parameters (Tables 88 and 89). For each scenario, all subsystems are considered operable except for the storage and recovery unit and the residue separation module. Also, the electrostatic precipitator is considered to be installed and operational as a replacement to the gas scrubber system. A discussion of how these parameters were developed follows.

As illustrated in Table 88, the operating status of the plant has been broken into four categories: downtime, heating and cooling of the process area, standby, and normal processing. Each scenario reflects a different level of plant operation.

Scenario 1 is based on actual plant operating history during the 9-month period from November 1976 to July 1977. During this period, the plant operated an average of less than 2 weeks continuously, and it was shut down approximately 6 days between runs. This average cycle continued throughout the period monitored. Thus, during the course of a year, the plant would be shut down 24 times for a period of 6.5 days per shutdown. Furthermore, each time the plant was shut down, there would be an accompanying 1-day period for cooling the system before the downtime, and a 1-day period for heating the system in preparation for operation. The 24 shutdowns therefore lead to an additional 48 days of plant unavailability. During operation it was decided to halt the processing of waste on Sundays to allow the staff to perform necessary maintenance functions. Process temperatures were maintained by firing fuel oil. In addition to the 33 days of nonscheduled standby, this scheduled standby time would account for yet another 23 days per year of plant unavailability. Emergency maintenance or process deviations (upsets)

TABLE 89. OPERATING AND MAINTENANCE UNIT COST DATA*

Item	Amount
Salary rates (annual, FY 77-78):	
Plant manager	$24,250
Plant supervisor	20,061
Clerk typist	7,572
Chief operators	16,277
Field operators	14,765
Ram operators	14,765
Equipment operators	9,518
Laborers	8,570
Scalemen	7,313
Engineers	17,326
Laborers/chauffeurs	8,216
Maintenance supervisor	17,327
Electricians	10,360
Mechanics	12,728
Welders	10,742
Oilers	8,216
Instrument technicians	17,450
Employee benefits rate (% of salary costs):	16.74
Fuel rates:	
No. 2 fuel oil	$0.083/ℓ
Gasoline	0.095/ℓ
Diesel fuel	0.092/ℓ
Electricity rate	$0.03/kwh
Water and sewer rates (quarterly basis):	
First 141,500 ℓ consumed	$0.127/1,000 liters
Next 1,275,000 ℓ consumed	0.079/1,000 liters
Any additional water consumed	0.053/1,000 liters
Chemical costs:	
Sulfite	$0.616/kg
Chelate	1.210/kg

* All cost information obtained between 5/77 and 7/77.

would account for an additional day and a half of standby. Thus on a yearly basis, the plant would be available for a total of 104 days of onstream time (365 days minus 157 days of downtime, 48 days of heating and cooling, and 56 days of standby).

The operating status changes in scenario 2 were based on an extension of the existing plant operation with an expanded operating staff and more efficient administrative procedures. It appears likely that changes in plant operation can increase the average continuous plant operating period to slightly over a month. If this is assumed, the number of maintenance downtimes would be approximately eight per year. If the number of downtimes are reduced, the duration of each will increase. Therefore, it is assumed that each duration will average eight days, yielding a total downtime of 64 days. Heating and cooling periods remain at 2 days per downtime, yielding a total of 16 days for heating and cooling. Standby time on Sunday could be eliminated by expanding the staff to the proper size. The final assumption made for this scenario is that standby time for maintenance and operational emergencies can be reduced by 21 days. As a result, the total available operating time is 264 days (365 days less 64 days downtime, 16 days heating and cooling, a[illegible] days standby).

The assumptions made for scenario 3 are based on the most optimistic operating conditions likely to occur, given the projected equipment improvements presently being initiated. This scenario assumes an increase in labor productivity and a market for all of the steam produced. The operating status of scenario 3 provides for quarterly, 1-week maintenance shutdowns, accounting for 27 days of downtime. The heating and cooling periods are, again, 2 days each, accounting for an additional 8 days of downtime. It is assumed that annual emergency standby time can be reduced to 18 days under optimal conditions. These assumptions provide for a total available operating time of 312 days (365 days less 27 days of downtime, 8 days of heating and cooling time, and 18 days of emergency standby). This estimate closely corresponds with Monsanto's original projections for the plant's level of operation, but was determined on an independent basis.

Table 90 illustrates the projected operating and maintenance costs in accordance with EPA's Accounting Format. Each scenario shows wide variations in cost per Mg throughput, which are primarily attributed to the differences in the operating reliability of the plant Projected annual operating and maintenance costs do not differ greatly for any of the scenarios, but the projected number of Mg processed under each scenario depends on the number of scenario operating days and has a major effect on cost per Mg.

Another major influence is that all material-related costs except fuel (i.e., chemicals, water and sewer, and electricity) increase in proportion to the number of tons processed. Fuel costs for Scenario 2 and 3 are less than Scenario 1 because of the decline in the number of days of standby, and heating and cooling. Although scenario 1 has fewer operating days, the increased fuel consumption during standby, and heating and cooling operations results in higher fuel costs.

TABLE 90. PROJECTED ANNUAL OPERATING AND MAINTENANCE COSTS*

Item	Scenario 1	Scenario 2	Scenario 3
Salaries†	$428,000	$569,000	$457,000
Employee benefits†	72,000	95,000	77,000
Fuel§	700,000	558,000	570,000
Electricity	293,000	463,000	523,000
Water and sewer	20,000	35,000	43,000
Maintenance	1,024,000	972,000	1,025,000
Chemicals	3,000	8,000	11,000
Residue removal	77,000	77,000	77,000
Other overhead	196,000	196,000	196,000
Total annual operation and maintenance costs	$2,813,000	$2,973,000	$2,979,000
Operating and maintenance costs/Mg	$42.00	$14.60	$11.00

* 1977 dollars.

† Excludes those salary and benefit costs applicable to residue removal.

§ Excludes input fuel costs applicable to residue removal.

Operating and maintenance costs were then normalized in accordance with EPA's Accounting Format guidelines. The normalized costs roughly coincide with the projected scenario costs and are presented in Appendix C.

Finally, projected Scenario 1 operation and maintenance costs were allocated to the seven EPA established cost centers as defined in the Request for Proposal (RFP) (Table 91). Costs were initially allocated to all cost centers except the residue separation module. General plant costs were then allocated to the remaining cost centers on a proportional basis determined by each cost center's existing dollar amount.

After costs were allocated to the five cost centers, it was then possible to determine separately the annual operating cost of waste and preparation and energy recovery. The annual operating cost of waste preparation is estimated at $641,000, and that of energy recovery is estimated at $2.2 million.

CAPITAL COSTS

Capital costs billed for the pyrolysis plant were identified through examination of the City of Baltimore's accounting records. The capital expenditures related to the pyrolysis plant are charged to Capital Projects

TABLE 91. OPERATING AND MAINTENANCE COSTS PER COST CENTER (SCENARIO 1)

Cost classification:	Total cost	Receiving	Size reduction	Storage and recovery	Thermal processing	Energy recovery	General plant
Salaries	$ 428,000	$ 22,000	$ 14,000	--	$ 44,000	--	$348,000
Employee benefits	72,000	4,000	2,000	--	7,000	--	59,000
Fuel	700,000	--	--	--	688,000	--	12,000
Electricity	293,000	5,000	34,000	$ 5,000	215,000	$ 10,000	24,000
Water and sewer	20,000	--	4,000	--	6,000	10,000	--
Maintenance	1,024,000	102,000	105,000	85,000	479,000	253,000	--
Chemicals	3,000	--	--	--	--	3,000	--
Residue removal	77,000	--	--	--	77,000	--	--
Other overhead	196,000	--	--	--	--	--	196,000
Total	2,813,000	133,000	159,000	90,000	1,516,000	276,000	639,000
General plant allocations:							
Salaries*		69,600	69,600	69,600	69,600	69,600	--
Remaining costs†		17,800	21,200	11,900	203,100	37,000	--
Total		87,400	90,800	81,500	272,700	106,600	--
Grand total	2,813,000	220,000	250,000	171,000	1,789,000	383,000	--

* Salaries were distributed equally to all cost centers.

† The remaining general plant costs were allocated on a pro rata basis.

Fund accounts. All of Monsanto's Original Contract expenditures and most, but not all, of the Supplemental Agreement expenditures are contained in these accounts.*

Once expenditures relating to the capital costs were ascertained, a research and review of the Capital Extract listing was undertaken. Through an examination of selected source documents relating to the voucher/check numbers, approximately 98 percent of the Extract costs were researched. Expenditures were investigated and scrutinized to determine whether they were

a. Properly chargeable to the project;
b. Properly classified as capital expenditures as opposed to operating expenses; and
c. Materially accurate for reclassification per EPA Accounting Format and cost centers.

During the detailed review, adjustments to the reported amounts were necessary because certain operating and maintenance costs were charged as capital expenditures, and vice versa.

Because of insufficient data, many expenditures cannot be separated as to their construction versus real equipment components. To segregate costs by construction and real equipment, it is necessary to have access to engineering estimates that include the labor input factor per equipment item. These data were not available, however, this situation was particularly acute for expenditures related to the Supplemental Agreement. For the most part, the Supplemental Agreement invoices exhibited integrated cost items encompassing both construction and real equipment. As a result, certain integrated costs are put under one cost classification.

Results of the capital cost analysis in accordance with EPA's Accounting Format are illustrated in Table 92. The net capital costs total $20.5 million. This figure results from adding the unbilled costs incurred by Monsanto to the costs recorded in the Capital Expenditures Extract. Another interesting point is that construction and real equipment costs account for 85 percent of the total costs.

Capital Cost Adjustments

To facilitate economic comparisons with other resource recovery systems, the capital costs were adjusted according to the Accounting Format to reflect more accurately the costs that would be incurred if the plant were duplicated elsewhere. Thus as part of the financial review of the capital costs incurred by the pyrolysis plant, an investigation of certain cost exclusions and additions to the project was performed. These additional adjustments include the following:

---

* As of March 3, 1977, costs of $404,593, which were incurred by Monsanto for the construction of the plant, were not recorded in the Capital Expenditure Extract.

TABLE 92. A SUMMARY OF EPA CAPITAL COST CLASSIFICATIONS

Title description	Land	Site preparation	Design	Construction	Real equipment	Other equipment	Financing and legal	Cost not researched	Total
#2 Extra work	--	$121,343	$11,500	$194,243	$380,854	$95,499	--	--	$803,439
#3 Design studies	--	--	18,165	--	--	--	--	$41,497	59,662
#4 Site	$486,411	27,540	--	--	--	--	--	63,081	577,032
#5 Inspection	--	--	--	--	--	--	--	5,345	5,345
#6 Structures and improvements:									
original contract	46,208	400,991	1,144,040	6,708,838	5,741,248	599,765	$64,000	36,910	14,742,000
supplemental agreement	--	--	--	3,804,385	--	--	--	--	3,804,385
other costs	45,870	--	--	--	--	--	147	55,064	101,081
#7 Utilities	--	--	--	27,898	--	--	--	21,611	49,509
#8 Furniture and equipment	--	--	--	--	--	--	--	3,199	3,199
#9 General	--	--	--	--	--	--	--	48,461	48,461
Additional equipment	--	--	--	--	10,758	250,763	--	76,782	338,303
Total	578,489	549,874	1,173,705	10,735,364*	6,132,860†	946,027	64,147	351,950§	20,532,416¶

* $4,108,039 of these costs include both real equipment and construction costs that cannot be separated.

† $371,587 of these costs include both real equipment and construction costs that cannot be separated.

§ The $351,950 represents costs not researched through examination of vouchers and is only 1.7% of the total costs.

¶ This sum includes $404,593 of unbilled supplemental agreement costs.

- -- Exclusion of unique and nonrecurring cost;
- -- Restatement of contributed or nominal cost items;
- -- Exclusion of costs attributed to the residue separation and gas scrubber systems;
- -- Inclusion of costs attributed to the construction of an electrostatic precipitator;
- -- Inclusion of costs attributed to residue disposal;
- -- Inclusion of indirect costs; and
- -- Restatement of costs in 1977 dollars.

These adjustments account for the plant's experimental status, the inoperative and replaced plant subsystems, and the inclusion of specified EPA cost elements not included in the Capital Expenditure Extract. The cost exclusions/additions relating to replaced and inoperative subsystems are consistent with the scenarios developed for the projection of operating and maintenance costs. The net impact of these adjustments in the capital cost classifications are illustrated in Table 93.

Capital costs incurred and subsequently adjusted were then classified according to EPA guidelines set forth in the Accounting Format. The estimated useful life of the facility and the total interest to be paid had to be determined to complete EPA's capital cost format.

Estimated Useful Life of the Facility

The useful life of the facility was determined through reference to Internal Revenue Service (IRS) guidelines for depreciable assets. The IRS depreciation regulations, as set out in Revised Procedures 72-10, state that the useful life for solid waste disposal plants has a lower limit of 14.5 years. With due consideration of the experimental nature of the pyrolysis plant, utilization of the lower limit seems appropriate.

As a means of tesing the validity of the 14.5 years useful life, inquiries were made of select vendors (Table 94).

Based on the cost of equipment items in Table 94, the estimated useful life of the facility is 17 to 18 years. This does not greatly differ from the IRS lower limit.

Interest to be Paid

The Baltimore landgard project was primarily financed through: (1) proceeds from the sale of city-owned real estate that was designated specifically for capital and economic development (approximately $6 million), (2) grants obtained from the State of Maryland ($4 million), and (3) the Federal Government ($7 million).

Since the interest expense associated with the construction of the plant was minimal, a cost was inputted that would represent total debt financing charges. The latest issuance of debt in the City of Baltimore was in April 1977. The effective yield on the bond was 5.3 percent. If this most

TABLE 93. CAPITAL COSTS (EXCLUSIONS/ADDITIONS)

Calibration	Land	Site preparation	Design	Construction	Real equipment	Other equipment	Finance and legal	Other costs	Total capital cost
Costs before exclusions/ additions	$578,489	$549,874	$1,173,705	$10,735,364	$6,132,860	$946,027	$64,147	$351,950	$20,532,416
Original contract cost items restated	573,321	505,030	1,045,764	9,985,088	5,490,799	878,953	56,990	347,822	18,883,767
Supplemental agreement cost items restated	573,321	505,030	1,045,764	6,900,571	5,490,799	878,953	56,990	347,822	15,799,250
Exclusion of material recovery system costs	573,321	505,030	1,045,764	6,361,182	4,998,970	878,953	56,990	347,882	14,768,032
Exclusion of gas scrubber system costs	573,321	505,030	1,045,764	5,969,647	4,694,199	878,953	56,990	347,822	14,071,726
Inclusion of ESP costs	573,321	505,030	1,045,764	7,409,687	5,825,659	878,953	56,990	347,822	16,643,226
Inclusion of imputted landfill costs:									
Scenario 1	693,557	505,030	1,072,817	7,511,887	5,843,694	878,953	56,990	380,887	16,943,815
Scenario 2	935,056	505,030	1,127,154	7,717,161	5,879,919	878,953	56,990	447,299	17,547,562
Scenario 3	1,054,264	505,030	1,153,976	7,818,488	5,897,800	878,953	56,990	480,081	17,845,582
Inclusion of imputted finance charge:									
Scenario 1	693,557	505,030	1,072,817	7,511,887	5,843,694	878,953	395,866	380,887	17,282,691
Scenario 2	935,056	505,030	1,127,154	7,717,161	5,879,919	878,953	407,941	447,299	17,898,513
Scenario 3	1,054,264	505,030	1,153,976	7,818,488	5,897,800	878,953	413,902	480,081	18,202,494
Costs restated in 1977 $:									
Scenario 1	849,304	668,975	1,448,709	9,454,472	7,497,866	1,153,825	416,364	471,935	21,961,451
Scenario 2	1,117,368	668,975	1,509,023	9,682,326	7,538,076	1,153,825	428,439	545,652	22,643,684
Scenario 3	1,249,689	668,975	1,538,795	9,794,799	7,557,924	1,153,825	434,400	582,040	22,980,447

TABLE 94. EQUIPMENT COSTS AND USEFUL LIFE REPORTED BY SELECT VENDORS

Description	Cost	Useful life (years)
Storage & recovery unit	$367,300	20
Waste heat boilers	829,821	20
Kiln	1,336,209	10
Waste Collector conveyor	305,674	20
Waste gas fan	149,618	20
Electrostatic precipitator	2,571,500	20

recent interest rate is used and a 20-year maturity on the bonds is assumed, the inputted finance costs for the project are derived for each of the scenario costs according to EPA guidelines.

The summary capital costs according to EPA's Accounting Format are presented in Table 95. Again, wide variations occur in costs per Mg, primarily because of projected differences in the operating reliability of the plant.

All All capital costs identified throughout the Capital Expenditures Extract, as well as additional equipment expenditures, were separately researched for reclassification by cost center.

Summary cost center distributions are presented in Tables 96 and 97. Table 96 illustrates cost center distribution before the cost exclusions and additions. Table 97 presents the final capital cost allocation for each of the three scenarios with the inclusion of the adjustments. The conversion of these cost center summaries into subsystem costs in accordance with EPA's RPF is shown in Table 98.

Nearly 75 percent of the costs pertain to the construction of the energy recovery subsystem. The thermal processing module separately accounts for approximately 50 percent of the total plant capital costs, whereas the energy recovery module accounts for 25 percent of total plant capital costs.

The Accounting Format provides guidelines and instructions for converting costs to a normalized basis. The results of this normalization for the pyrolysis plant are presented in Appendix C.

Because detailed cost information is unavailable, only 10 percent of the total capital costs could be normalized. Cost components that could be normalized include construction, real equipment, and other equipment. The construction cost could not be adjusted because of a lack of information concerning man-hours and overall labor input. Equipment costs could not be adjusted because of lack of information for segregating freight costs.

TABLE 95. PROJECTED SCENARIO CAPITAL COST SUMMARY

Item	Scenario 1	Scenario 2	Scenario 3
Capital cost ($):			
Land	$ 849,000	$ 1,117,000	$ 1,250.000
Site preparation	669,000	669,000	669,000
Design	1,449,000	1,509,000	1,539,000
Construction	9,454,000	9,682,000	9,795,000
Real equipment, including replacements	7,498,000	7,538,000	7,558,000
Other equipment, including replacements	1,154,000	1,154,000	1,154,000
Contingencies			
Startup and working capital			
Financing and legal	416,000	428,000	434,000
Other costs	472,000	546,000	582,000
Total initial capital investment ($)	21,961,000	22,643,000	22,981,000
Estimated useful life of facility (years)	14.5	14.5	14.5
Total interest to be paid ($)	13,684,000	14,109,000	14,319,000
Total capital cost ($)	35,645,000	36,752,000	37,300,000
Annual capital cost ($)	2,458,000	2,535,000	2,572,000
Annual throughput (Mg)	67,000	203,000	270,000
Capital cost per Mg ($)	36.70	12.50	9.50

TABLE 96. SUMMARY COST CENTER DISTRIBUTIONS

Title descriptions	Receiving	Size reduction	Storage and recovery	Thermal processing	Energy recovery	Residue separation	General plant	Other costs*	Total
#2 Extra work	--	--	--	--	$ 127,645	--	$ 675,794	--	$ 803,439
#3 Design and studies	--	--	--	--	--	--	18,165	$ 41,497	59,662
#4 Site	--	--	--	--	2,840	--	511,111	63,081	577,032
#5 Inspection	--	--	--	--	--	--	--	5,345	5,345
#6 Structures and improvements:									
original contract	$1,339,006	$1,230,067	$1,122,649	$4,400,025	3,083,785	$857,626	2,708,842	--	14,742,000
supplemental agreement	13,756	296,431	92,614	2,628,861	330,542	24,400	417,781	--	3,804,385†
other costs	--	--	--	--	--	--	46,017	55,064	101,081
#7 Utilities	--	--	--	--	--	--	27,898	21,611	49,509
#8 Furniture and equipment	--	--	--	--	--	--	--	3,199	3,199
#9 General	--	--	--	--	--	--	--	48,461	48,461
Additional equipment	2,605	5,547	--	2,606	--	17,941	232,822	76,782	338,303
Total	1,355,367	1,532,045	1,215,263	7,031,492	3,544,812	899,967	4,638,430	315,040	20,532,416

* Not researched or identified.

† This sum includes $404,593 of unbilled supplemental agreement costs.

TABLE 97. CAPITAL COSTS PER EPA COST CENTER INCLUDING ADJUSTMENTS*

Cost center	Scenario 1	Scenario 2	Scenario 3
Receiving	$ 2,197,000	$ 2,198,000	$ 2,141,000
Size reduction	2,236,000	2,237,000	2,238,000
Storage and recovery	1,827,000	1,828,000	1,829,000
Thermal processing	10,284,000	11,075,000	11,466,000
Energy recovery	5,417,000	5,305,000	5,307,000
Total	21,961,000	22,643,000	22,981,000

* Dollar amounts for receiving and energy recovery decrease because of the method of allocation. The indirect costs (general plant) are allocated based on each remaining cost center's relative percentage of direct costs. As thermal processing direct costs increase, their subsequent share of the interest costs increases, resulting in decreased costs for receiving and energy recovery.

TABLE 98. SUBSYSTEM CAPITAL COSTS

Scenario	Waste preparation	Energy recovery
1	$6,260,000	$15,701,000
2	6,263,000	16,380,000
3	6,208,000	16,773,000

REVENUES

The City of Baltimore maintains separate accounts for recording revenue from sales of ferrous metals, non-ferrous metals, and steam produced by the pyrolysis plant. But because steam is the only product being sold, a complete economic analysis of revenues could not be performed. Accordingly, the scenario approach has been followed for projected steam revenues only.

The City of Baltimore entered into a contract with the Baltimore Gas & Electric Company for the sale of steam generated by the plant. The contract provided the City with a market for most of the steam produced, thereby limiting supply and demand problems. The contract provided for a variable price for the steam based on the fluctuating price of No. 6 crude oil. With the contract formula, the latest available price for steam approximates $6.88/1000 kg ($3.13/1000 lbs) of steam. When this figure is applied to the individual scenarios, the following annual revenues are derived:

Scenario:	Steam revenue
1	$ 978,432
2	2,176,612
3	3,435,494

The differences in steam revenues are primarily attributed to the greater number of operating days in scenarios 2 and 3, which cause greater steam production. The steam revenue from Scenario 3 is much greater than that of Scenario 2 because Scenario 3 assumes that market demand is strong throughout the year and that all steam produced can be received by the market.

Steam revenues were then normalized per EPA guidelines. The guidelines call for using a price of $3.31/1000 kg ($1.50/1000 lbs) of steam. This figure results in the following annual revenues for each scenario:

Scenario:	Steam revenue
1	$ 470,000
2	1,046,448
3	1,651,680

NET OPERATING COSTS

The net operating costs for each scenario were computed by deriving total costs and revenues. The scenarios' projected and normalized costs were transferred from the pertinent exhibits yielding total costs. Revenues per Mg were derived by dividing the revenues under each scenario by annual throughputs. The net operating costs are presented in Table 99.

In evaluating the net operating cost per Mg, certain factors should be considered. First, the figures are not indicative of the cost per Mg incurred by the City of Baltimore. The City's costs are much less because of Federal and State project funding. Second, the manner in which costs are treated does not totally conform with GAAP.

If costs were presented in accordance with GAAP, the cost on a per-Mg basis would be less because only depreciable assets would be included in the accumulation of net operating costs. Land and site preparation costs would not be recognized as contributing to the net operating cost. Although other Accounting Format variations from GAAP occur, they do not significantly affect the net operating cost.

TABLE 99. PROJECTED COST SUMMARY[*]

Cost category	Scenario 1[†]		Scenario 2[§]		Scenario 3[¶]	
	($/Mg)	($/ton)	($/Mg)	($/ton)	($/Mg)	($/ton)
Capital costs	$22.60	$20.50	$ 7.70	$ 7.00	$ 5.90	$ 5.30
Interest	14.10	12.80	4.80	4.30	3.60	3.30
Operating and maintenance costs	42.00	38.10	14.60	13.30	11.00	10.00
Total costs	78.70	71.40	27.10	24.60	20.50	18.60
Revenues	14.60	13.20	10.70	9.70	12.70	11.50
Net cost	64.10	58.20	16.40	14.90	7.80	7.10

[*] In 1977 dollars.

[†] Annual throughput is 67,000 Mg/year (74,000 tons/year).

[§] Annual throughput is 203,000 Mg/year (223,000 tons/year).

[¶] Annual throughput is 207,000 Mg/year (300,000 tons/year).

SECTION 6

ADMINISTRATIVE ASSESSMENT

INTRODUCTION

Nontechnical problems were encountered in the Baltimore Landgard® demonstration as a result of the project's overall administrative structure. This structure involved several diverse groups: (1) the Federal government, (2) the State government, (3) the City of Baltimore municipal government, and (4) the industrial designer of the facility, Monsanto EnviroChem. The complications originated from the number of groups involved, their diverse internal organizations, and their mode of interaction.

This situation resulted in a highly complex overall organization that caused time-consuming and confusing decisions. The operating staff was at times confused about who had authority over the operation and who was directing their efforts. The confusing and laborious decision making process had a negative impact on the effectiveness of the operating staff, who needed to take decisive action in emergency situations that arose during the demonstration. The turnover rate in personnel created a lack of continuity and resulted in redundant actions that increased confusion and delayed the demonstration.

All parties involved in the project were attempting to achieve their own goals, which were sometimes at odds.

PARTIES INVOLVED

The four parties involved in the Baltimore Landgard® demonstration facility were:

1. The Federal government, who provided \$6 million in funding for the demonstration through EPA;

2. The State government, which provided a grant/loan of \$4 million to the City of Baltimore for construction of the facility to be repaid from revenues derived from selling recovered resources at the facility;

3. The City of Baltimore, who owned and operated the facility; and

4. Monsanto EnviroChem, the system designer who was responsible for the design, construction, and startup of the facility and who guaranteed its performance.

The City, Monsanto, and EPA all had an interest in having the facility in operation as early as possible. The City required a plant that could reliably process municipal solid waste to replace their Reedberg incinerator and landfill, which was to be closed in 1974. Monsanto wanted a marketing tool to establish their credibility in the field of resource recovery from solid waste. And EPA wanted an operating facility to prove that resource recovery was a viable alternative to landfill disposal of solid waste. The wide publicity that the project received further increased the pressure on everyone to expedite the startup. This need precluded the testing and experimentation necessary to refine the process equipment and the process operation to the level required for optimum system operation. The demonstration thus failed to show the potential reliability of the Landgard® pyrolysis process. Rather, it showed the level of operation for the original design configuration of the process, independent of refinements that should have been made as experience was gained.

ORGANIZATION OF THE GROUPS INVOLVED

EPA Organization

The Federal involvement in the project was the result of funding made available to the City of Baltimore from the EPA grant. Five percent of the Federal grant money was withheld from the project to guarantee compliance of the City and Monsanto EnviroChem with the terms of the grant.

Monsanto Organization

The Monsanto organizational structure was established to supply technical and administrative support during the startup of the demonstration facility and to supervise plant operation through the demonstration period. This group was supported by technical and administrative groups at the main offices of Monsanto EnviroChem at their process group center in Chicago, Illinois. At the beginning of the demonstration, the onsite team consisted of the project manager, a process control engineer, a design engineer, and two inexperienced engineers who were also new employees. The instrument/electrical capability was supplied by a contract instrument technician whose primary assignment was to perform the initial checkout of the plant instrumentation as construction was completed. In addition to supervising the operation during the startup and demonstration periods, the Monsanto staff also had the responsibility for training the plant operating staff before startup. The Monsanto staff was likewise to supply the shift engineering capability during plant startup.

Because of the degree and number of problems encountered during the startup period, an expansion of the staff supplied by Monsanto was required.

The first addition consisted of an experienced Monsanto plant maintenance and operating person, and an experienced Monsanto instrument man. As the demonstration progressed, it was realized that complete design and construction capability would be required onsite for the necessary modifications. To achieve this end, the administration of the project was delegated to a higher level of management in Monsanto, and an onsite assignment of the supervisor of project management was made by Monsanto. In addition, the entire process engineering group located in St. Louis was brought onsite, thus adding three more process engineers to the field team. Design capability was provided by assigning the original project engineer, two design engineers, a contract designer, and the supervisor of the electrical engineering group to the field site. An office manager and assistant construction superintendent were also added to the field team. These personnel were added to the field team over a period of 6 to 12 months after project initiation. Although this increased staff did much to salvage the project, it would have been advisable to supply them at an earlier stage of the project.

The relocation of company personnel to a temporary job site remote from the home offices had a negative effect on the performance of the employees assigned to the site. This factor is typical of all startup situations and should be taken into account during the planning stages of the work. The condition was aggravated during the Baltimore demonstration because of the indeterminate duration of the assignments. Those employees who were assigned temporarily to the project created a problem of discontinuity. Because tasks were not necessarily completed by the person who initiated it, the efficiency with which assignments were carried out was affected negatively.

City Organization

As shown in Figure 97, the administration of the Baltimore Landgard® pyrolysis plant falls under the Department of Public Works of the City of Baltimore. Specific responsibility for the plant is assigned to the Sanitation Division through the plant manager, who is assigned onsite. During the demonstration period, however, the Sanitation Division staff operated in conjunction with an onsite project engineer who reported directly to the head of the Department of Public Works. This administrative structure was in effect during the construction and startup phase of the demonstration facility. The main task of the project engineer was to represent the City in all decisions made by Monsanto EnviroChem and EPA concerning plant operation. This project engineer was assigned onsite, and in practice, he superseded the plant manager in the operational responsibility for the facility.

As further detailed in Figure 97, the plant superintendent reports to the plant manager and is responsible for the process operation of the plant. He is reported to by the chief operators and the labor foreman. The maintenance supervisor also reports to the plant manager. The plant mechanics and instrument/electrician report to him, although they follow the shifts with the chief and field operators. The major problem encountered with this type of organization is that the maintenance and operation functions are never formally coordinated until the top level of plant management is reached.

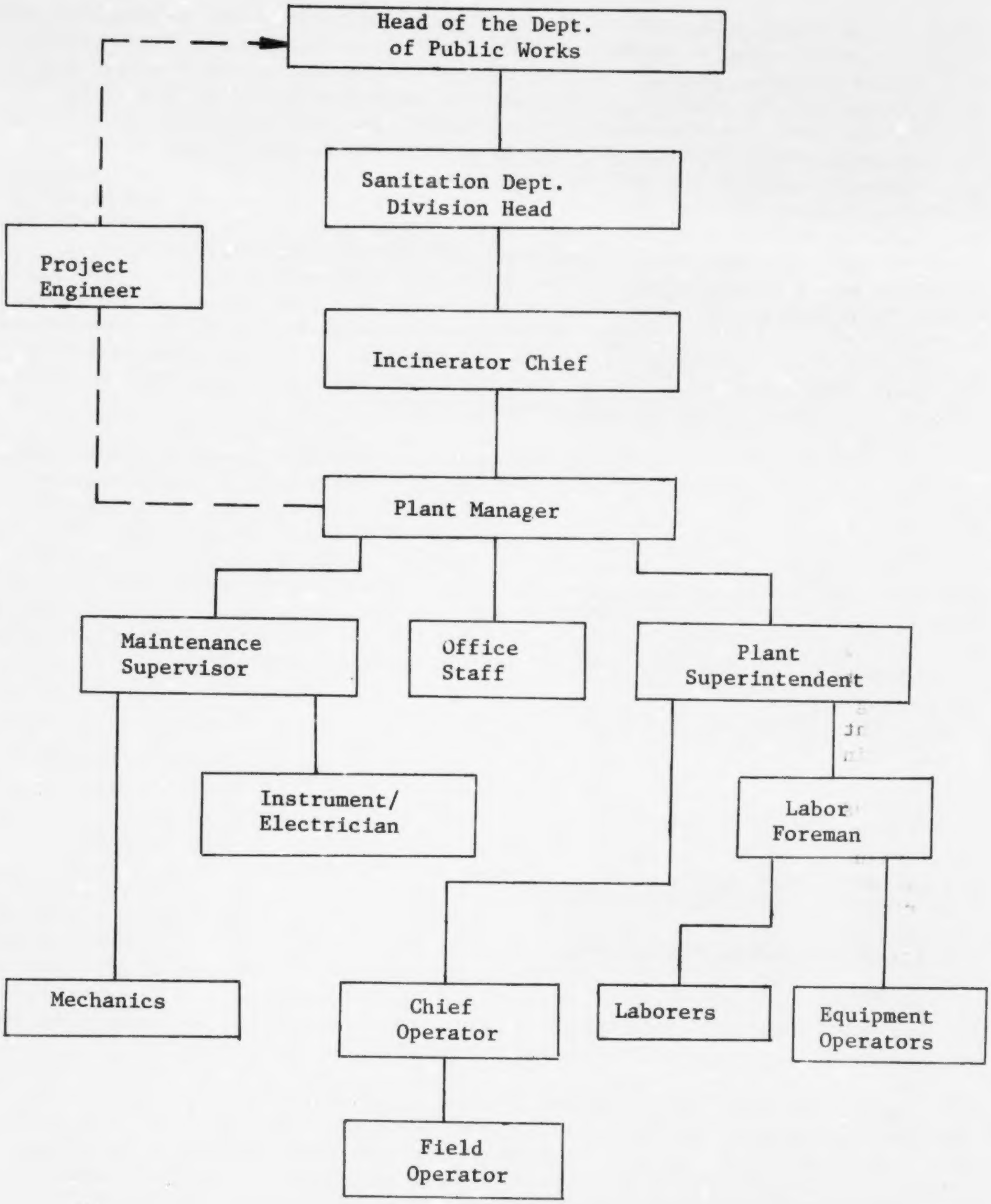

Head of the Dept. of Public Works
Sanitation Dept. Division Head
Project Engineer
Incinerator Chief
Plant Manager
Maintenance Supervisor
Office Staff
Plant Superintendent
Instrument/ Electrician
Labor Foreman
Mechanics
Chief Operator
Laborers
Equipment Operators
Field Operator

Figure 97. City administration structure pertaining to pyrolysis plant.

Such a setup interferes with expedient decision making in that it precludes certain actions during the shifts because no individual present is responsible for coordinating maintenance and operation. Delays in decision making and frustration in plant operators result from this lack of authority.

Another difficulty encountered in the City's organizational structure as the temporary project engineer who effectively ran the project by bypassing the normal chain of command. The results were confusion among the City personnel and lack of committment and involvement on the parts of the plant manager and the head of the Sanitation Division. These passed-over executives were in charge of executing the methods of operation, but they had no part in establishing them. Thus, the plant manager tended to modify methods instituted by the project engineer as soon as the latter was replaced. When the plant manager and the head of Sanitation were later required to make decisions, their lack of involvement and experience made it necessary for them to begin the learning process at an inappropriate stage of plant operation.

Monsanto's supply of all engineering support during startup effectively bypassed another required City function -- that of engineering support to the operating staff. Again, the result was lack of committment and a need for City engineers to learn lessons that were mastered by Monsanto engineers earlier in the project. As a result of this structure, the City assigned no full-time engineer to the plant and developed no laboratory or quality control capability. This situation continued after the Monsanto personnel had departed from the job site, leaving the City with minimal experienced engineering capability with respect to the operation of the pyrolysis plant. A consultant hired by the City provided the project's only continuity in engineering.

Changes in the City staff during the course of the demonstration program created a lack of continuity in the decision making process. The impact of this situation was compounded by the existence of a City hiring freeze on all public works personnel. The project engineer and project manager were thus not replaced; instead, the plant superintendent was promoted to plant manager, and one of the chief operators became plant superintendent. Effective administration of the pyrolysis plant was thus severely hampered by the inability to hire employees with the requisite professional backgrounds. The hiring freeze also severely limited the maintenance and operating departments as the normal turnover of employees occurred. Operating and maintenance personnel who resigned or were transferred were not replaced, thus placing a greater burden on the already overworked plant staff. This situation can be directly related to subsequent downtime because of the need to schedule routine maintenance on Sundays. Because of the reduced personnel, operators and maintenance staff were required to work overtime to properly staff the plant.

City procurement and accounting procedures also created impediments to the project. The Baltimore procurement procedure (Figure 98) was a typical municipal design for coping with routine, fixed-budget projects; it did not employ the emergency procedures required in process plants. The Baltimore Landgard® facility is a moderately complex industrial process, and downtime

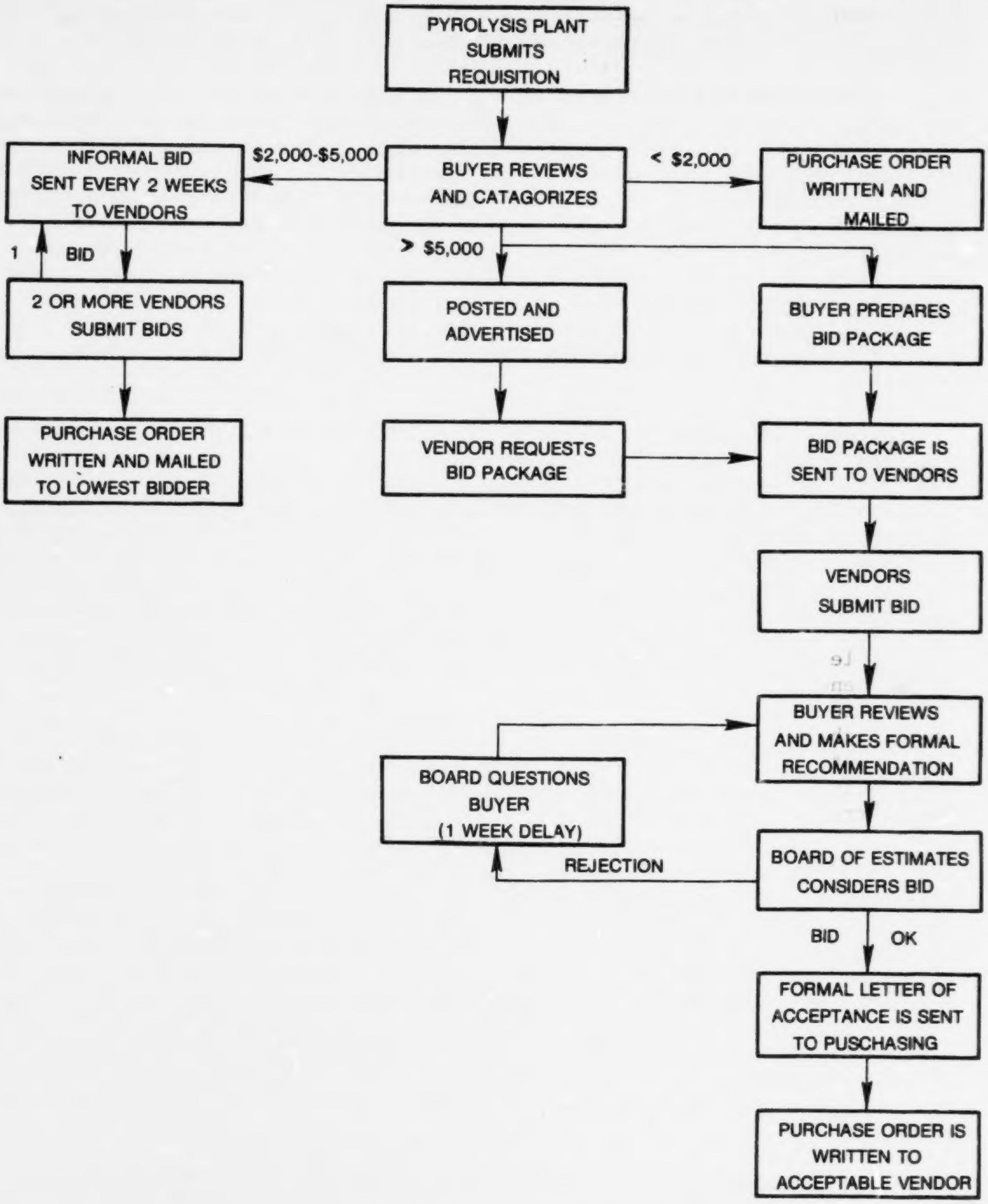

PYROLYSIS PLANT SUBMITS REQUISITION
BUYER REVIEWS AND CATAGORIZES
$2,000-$5,000
< $2,000
> $5,000
INFORMAL BID SENT EVERY 2 WEEKS TO VENDORS
PURCHASE ORDER WRITTEN AND MAILED
1
BID
2 OR MORE VENDORS SUBMIT BIDS
POSTED AND ADVERTISED
BUYER PREPARES BID PACKAGE
PURCHASE ORDER WRITTEN AND MAILED TO LOWEST BIDDER
VENDOR REQUESTS BID PACKAGE
BID PACKAGE IS SENT TO VENDORS
VENDORS SUBMIT BID
BUYER REVIEWS AND MAKES FORMAL RECOMMENDATION
BOARD QUESTIONS BUYER (1 WEEK DELAY)
REJECTION
BOARD OF ESTIMATES CONSIDERS BID
BID
OK
FORMAL LETTER OF ACCEPTANCE IS SENT TO PUSCHASING
PURCHASE ORDER IS WRITTEN TO ACCEPTABLE VENDOR

Figure 98. Original Procurement Procedure for the City of Baltimore

is indeed costly. But the Baltimore procurement procedures took an average of 4 weeks for requests over $2000. In an emergency, the most expedient procurement required at least 2 weeks to execute. The problem was aggravated by the fact that most purchases exceed $2000 for this size industrial facility. Because of the unworkable nature of this procedure, the City modified it after the demonstration period.

The accounting control techniques used by Baltimore and many other cities are also not conducive to the most efficient operation of solid waste resource recovery facilities. Since municipal operating departments seldom involve revenues, the budgetary systems do not directly account for any system operating income. System operations efficiency is thus difficult to measure, as is the relative attractiveness of alternate methods of disposal. Among the economic penalties resulting from downtime at the Baltimore plant were lost revenues of approximately $12,000 per day. But because there was no method in the City accounting system to relate this cost directly to plant operation, the City administration was unaware of the magnitude of this penalty.

The lesson to be learned is that planners and engineers must be aware of administrative requirements for the operation of resource recovery facilities. This knowledge must then be used to determine the feasibility of municipal operation and the need to modify the existing administrative systems.

OVERALL EFFECTS OF ORGANIZATION

While aff agencies involved, worked toward the successful performance of the denomstation, their particular interests, responsibilities, and orientation differed widely. Any decision-making had to be approved in a varying chain relationship by the City of Baltimore, Monsanto, and EPA. Consequently, their varying interests and perspectives caused delays, especially in the plant shutdown periods, and hampered plant operation and administrative functions.

The need for Monsanto to maintain technical credibility with both the City and EPA potentially interfered with effective decision making because of Monsanto's necessarily defensive posture regarding plant designs. In addition, the city's need for a reliable facility minimized the fact that the Landgard® facility was a demonstration project, and a prototype that required extensive testing and refinement. The City's position in all decisions was aimed at making the process operational in the near-term. Thus, it was unlikely that the process ever operated anywhere near optimum levels of performance during the demonstration.

CONCLUSIONS

In future implementations of resource recovery facilities, all parties involved should clearly delineate their goals and needs relating to the project. These goals must be compatible with those of the others involved in the endeavor. The nature of the project and the mode of execution must be carefully reviewed and planned so that the needs of all parties are adequately met. The structual organization of each entity involved must also be examined with a view to their functions in the project.

The arrangement whereby the City of Baltimore provided an operating staff to aid Monsanto in the checkout and startup of the facility proved to be overly complicated. Many of the difficulties encountered could have been avoided had the system designer carried the project through the acceptance testing stage without the active involvement of the client (the City of Baltimore). If the project agreement had been made incorporating this strategy at the beginning of the project, a more efficient execution could have been achieved. A conscious attempt to minimize the number of groups involved in the decision making process and to place the responsibility and authority for acceptable performance on one entity would have improved the probability of success.

A city that considers owning and operating a resource recovery facility should review its applicable administrative structures to determine their compatibility with the efficient operation of such a facility. Adequate contingencies should be allowed for extensive changes in manpower and operating budgets for first-of-a-kind units put in service. For the Baltimore facility, three to four times the originally estimated number of startup personnel were required, and the period needed for the demonstration was twice as long as originally estimated. The extensive modifications that were necessary nearly doubled the originally estimated cost of the facility.

SECTION 7

FUTURE PLANT

The demonstration facility at Baltimore has been evolving during the entire evaluation period, and the City of Baltimore is continuing this process to improve plant performance. As system reliability is improved, the concept is anticipated to become economically attractive. A likely configuration of a second generation process based on the experience gained at the Baltimore installation will be discussed in this section to show the level of complexity and investment required for a facility patterned after the Baltimore concept.

ONGOING AND PROPOSED MODIFICATIONS

The City of Baltimore is continuing to modify the pyrolysis facility to increase process reliability and to simplify operation and maintenance. Design and construction efforts involved in these modifications are being accomplished through joint funding from the City of Baltimore and the Federal government through monies made available by an Economic Development Administration Public Works Grant. The goals of these modifications are threefold: (1) to bring the stack emissions into compliance with State regulations, (2) to resolve those problems that have caused extensive plant downtime during the demonstration period, and (3) to simplify the overall process and thus reduce the potential for additional operational difficulties. Four major areas are being modified to accomplish these goals. First is the replacement of the entire gas scrubbing system with electrostatic precipitators. Second, the gas purifier is being redesigned from a slagging to a nonslagging operation. Finally, the storage and recovery unit and the residue separation module (which have not been operated by the City during the final stages of the demonstration) will be eliminated from the process (Figure 99).

The ensuing discussions will consider the motivation for the present modifications, a plant description of the work being performed, the advantages and disadvantages associated with each specific modification, and a hypothetical future-plant design.

Replace Gas Scrubbing System With Electrostatic Precipitators

The inability of the existing wet scrubber to control particulate emissions has required the replacement of the unit with electrostatic precipitators. A portable electrostatic precipitator has been tested on a portion of the boiler discharge gas stream at the plant and was found to perform acceptably.

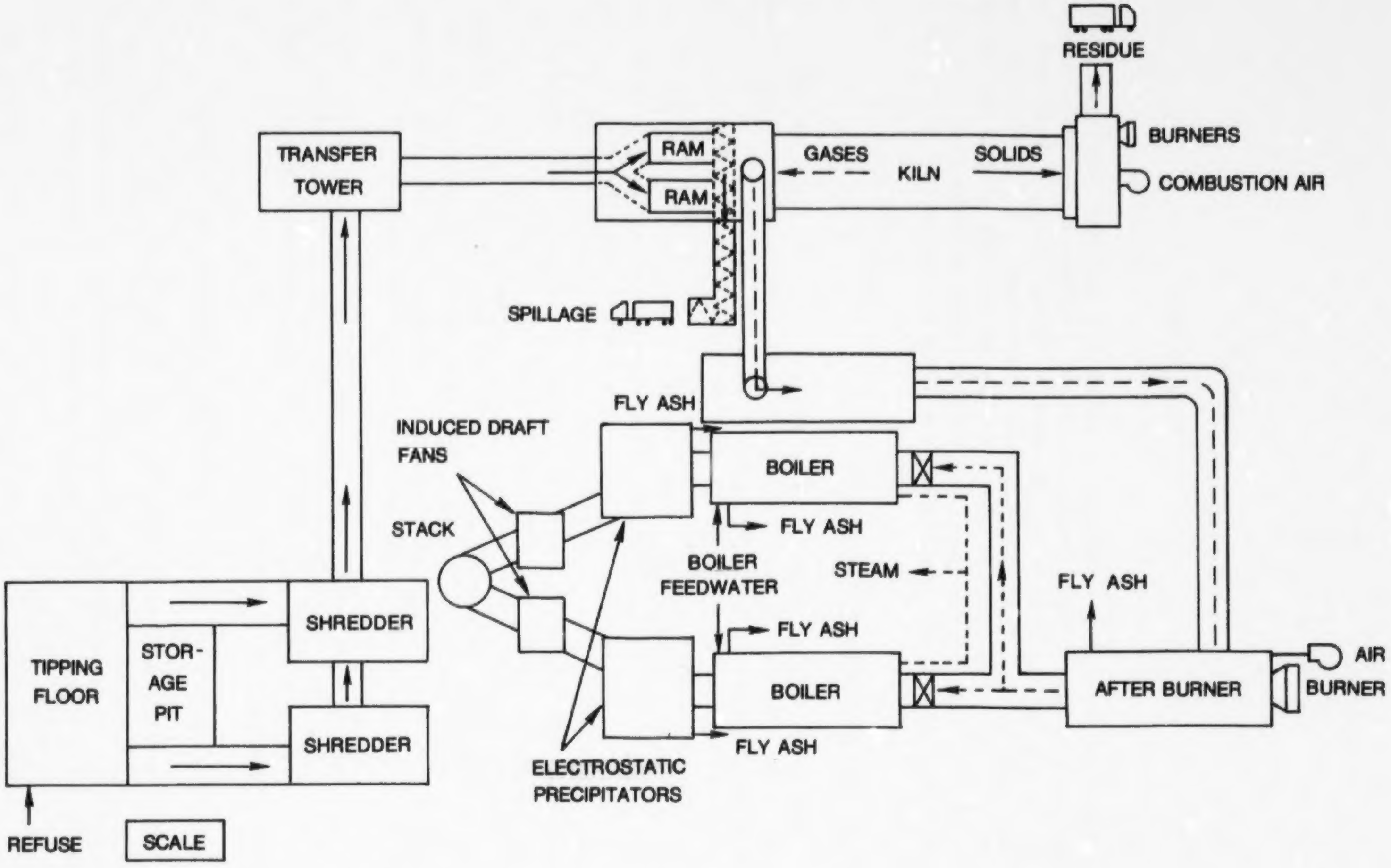

RESIDUE
BURNERS
COMBUSTION AIR
TRANSFER TOWER
RAM
RAM
GASES
KILN
SOLIDS
SPILLAGE
FLY ASH
INDUCED DRAFT FANS
BOILER
STACK
FLY ASH
BOILER FEEDWATER
STEAM
FLY ASH
FLY ASH
AIR
BURNER
AFTER BURNER
BOILER
FLY ASH
SHREDDER
TIPPING FLOOR
STOR-AGE PIT
SHREDDER
ELECTROSTATIC PRECIPITATORS
REFUSE
SCALE

Figure 99. Proposed future plant look.

Electrostatic precipitators have been applied extensively for the control of emissions from incinerators, and they are well proven in this application. The basic modification will involve removal of the wet gas scrubber and replacement with two parallel electrostatic precipitators. Because of corrosive components in the stack gas, it will be necessary to maintain a higher inlet temperature to the electrostatic precipitators than was the case with the wet scrubber, which neutralized any condensed acids. This higher temperature will be accomplished by removing the existing economizers. The present wet-gas induced draft fan will be replaced by two dry fans installed in parallel to provide redundancy. The dehumidifier system will be replaced by a tall stack to provide elevated discharge of the process gases. All of the auxiliaries associated with the scrubber; pumps, clarifier, etc. will also be removed.

To minimize the maintenance and operating requirement placed on the City's staff by installation of the electrostatic precipitator, the City has contracted with the equipment vendor for maintenance. This step should further improve the reliability of this section of the plant.

The primary advantage associated with the electrostatic precipitators is compliance with emissions regulations. The modification will eliminate the vapor plume accompanying the stack emission and the need for liquid and sludge handling equipment in the air pollution control area. A major cost saving will be realized through the elimination of the large caustic consumption associated with wet scrubber operation (the single largest operating expense associated with the plant). The dry system will eliminate the extensive downtime experienced because of problems with the wet-gas fan, and the corrosion and freezing problems in the wet-gas handling system.

The disadvantages associated with this modification include reduced boiler efficiency and increased power consumption because of the large electrical demand of the electrostatic precipitator. Both of these factors will have a deleterious effect on overall plant efficiency. Elimination of the wet scrubber system will also result in increased level of acid vapors and low chain hydrocarbons in the stack gas. The benefits of having a contracted maintenance agreement may be offset by the City's dependency on an external source for their maintenance requirements. Downtime could increase if the vendor does not respond promptly.

Gas Purifier Modification

The extensive downtime experienced as a result of slag tap-hole plugging during the demonstration has resulted in a new design for the gas purifier to transform it from a slagging to a nonslagging configuration. The existing operation of the vessel involves excessively high operating temperatures to maintain the slag material in a molten state so that it can flow to the slag tap-hole to be removed. These high operating temperatures have contributed to major refractory problems in the lining of the vessel.

The gas purifier modifications are designed to keep process temperatures in the vessel below the slag fusion temperature, thereby permitting operating of the vessel in the nonslagging mode. To accomplish this objective, the gas purifier will be relocated farther from the kiln to allow dissipation of sensible heat in the kiln off-gas. Heat dissipation will be accomplished through the increased heat transfer surface area of the ductwork between the kiln and the gas purifier. This reduction in the sensible heat of the off-gas will in turn contribute to a reduction in the process temperature in the gas purifier. An increase in the volume of the gas purifier and in the amount of excess combustion air supplied to the gas purifier will further reduce the reaction temperature in the vessel. This change is a direct extension of existing incinerator knowledge.

Equipment changes necessitated by the change from a slagging to a nonslagging operation will involve (1) replacement of the existing slag tap-hole and slag handling system with ash hoppers in the bottom of the reactor vessel, and (2) installation of a drag conveyor fly ash handling system. These changes should eliminate the need for the quench air inlets at the discharge of the gas purifier, since the temperature of the gases at this point will be compatible with the process temperature requirement at the boiler inlet.

The claimed advantage of this modification will be the elimination of refractory and thermocouple failures in the gas purifier resulting from the high operating temperatures and slag attack. This modification should greatly reduce downtime associated with gas purifier operation and accompanying maintenance costs. Downtime related to slag tap-hole plugging and slag handling equipment failures should also be eliminated with this modification. Furthermore, operation of the gas purifier at high excess air levels should simplify the control characteristics of the vessel. This modification will provide a safer work environment because of the lower design skin temperature.

The major disadvantage of this modification will be the decrease of thermal efficiency as a result of the increased heat losses designed into the equipment. Downtime may occur as the result of process upsets that cause elevated temperatures and subsequent formation of molten slag. When cooled, the slag will jam the fly ash handling equipment. The probability for such an eventuality is minor, but it should be considered in the design and operation of this equipment.

Elimination of the Storage and Recovery Unit

Because the storage and recovery unit failed to operate satisfactorily, the City has decided to eliminate it from the process stream. The primary problem in the unit has been the inability of the system to retrieve the material from the storage vessel at low storage volumes. To counter this difficulty and provide the required feed rate to the thermal processing area, the system must be operated at high speeds, a situation that results in drastically accelerated wear of the equipment. The floor of the storage silo is presently worn out after 6 months of operating time. The vendor has suggested several designs to remedy the problem at costs ranging from \$250,000 to \$700,000. The hesitancy of the vendor to guarantee the modifications has made the City decide that the risk is too great to justify the investment.

The equipment changes required to implement this modification involve utilization of the existing bypass system installed in the transfer tower. A belt scale had to be installed on the elevating conveyor before the bypass chute to measure the flow of waste to the thermal processing area. While the system is being operated in this mode, it will be necessary to operate only one shredder at a time to avoid overloading the kiln feed system. In this mode, the only control that the operators have over the feed rate to the thermal processing area is through the variable-speed conveyors that feed each shredder.

The advantages in replacing the storage and recovery unit are that a high-maintenance piece of equipment is eliminated, system energy consumption is reduced, and that operation of several pieces of equipment is eliminated thereby simplifying the overall process operation.

The disadvantages involved in implementing this modification are a reduced ability to control the input rate to the thermal processing area, limited throughput rate of 27 Mg per hour (30 tons per hour) vs. design of 38 Mg per hour (42 tons per hours), and the elimination of surge capacity after the shredders. In the event that the shredders or one of the transfer conveyors downstream of the shredders fails, the entire process must be shut down, since no storage capacity exists after the shredders. By locating the entire storage capacity of the plant in the receiving building, the storage capability is reduced, and 24-hour operation of the size-reduction module becomes necessary. Experience has shown a tendency for shredded waste to jam in the bypass ductwork, and some downtime is anticipated as a result of this condition during future operation of the system in the bypass mode. Modifications to the bypass ductwork would reduce the problem, but the City has no intention of making them at this time. Another negative aspect of eliminating the storage and recovery unit is that the automatic process control system is bypassed because the main sensing device in the control loop is installed as part of the storage and recovery system. There are no present plans for the City to replace or relocate this equipment.

Elimination of the Residue Separation Module

Elimination of the residue separation module involves replacement of all separation equipment in the existing area with a simple transfer station that will direct the flow of pyrolysis residue to dump trucks for subsequent landfill disposal. The primary reason for eliminating this processing area is the inability of the installed equipment to perform satisfactorily in the existing configuration.

This modification would involve installation of a dump chute and hopper, removal of building panels, and a change in the structural steel in the building. The area would need to be paved to allow trucks access to the dumping area. A relocation of the motor controls presently installed in the materials recovery building will be required, but most of these controls are involved in the residue separation equipment presently installed, and thus would be eliminated.

Advantages of eliminating the materials recovery process are reductions in labor, materials, and power necessary for plant operation. This modification also alleviates the need for further investment in modifications to the area. The existing method of loading residue trucks will be improved with the process occurring in an enclosed, paved area. This mode of operation will also allow for a wider variation in residue product quality than possible when the residue is separated, since separation equipment requires strict quality control of the product material to accomplish efficient separation. Finally, a major improvement achieved by eliminating the residue separation module is a simplification of the process.

The disadvantage of eliminating the materials recovery area is the loss of a revenue source that has growth potential as market conditions change in the future. This modification also increases the quantity of material to be disposed of, thereby increasing the disposal cost of this residue. The operating cost for this area will not be significantly reduced because of the necessity for operating 24-hour transportation of the residue to the ultimate disposal site. The increased moisture content of the transported material has resulted in spillage along public roadways between the plant and the disposal facility. This problem has already been the source of some complaints by residents along that route.

SECOND GENERATION FACILITY

The next generation resource recovery facility based on the rotary kiln concept will have a substantially different configuration than the Baltimore plant. This section considers possible configurations that the system might assume, based on the present state-of-the-art. An infinite number of alternate schemes could be suggested based on recent experience in the field of resource recovery from solid waste. The suggestions here, however, are primarily the result of specific experience gained in Baltimore.

Areas that performed acceptably and that are economically competitive with functionally similar processes are as follows:

1. Receiving area
2. Size reduction
3. Primary thermal processing area (rotary kiln)
4. Heat recovery area

Areas that failed to perform effectively in the existing configuration on either an economic or technical basis are:

1. Storage and recovery unit
2. Secondary thermal processing area (gas purifier)
3. Emissions control system
4. Residue separation module

For purposes of this discussion, it will be assumed that those areas operating acceptably will be retained in the second generation plant design. But, there are potential improvements that can be made to increase the operating efficiency of these units. Assuming that storage after the shredder is not necessary, the shredders should be resized to match the capacity of the thermal processing area to maximize waste throughput. This assumption is reasonable in view of operating experience that has shown the kiln feeders to provide sufficient surge capacity to accomodate variations in material feed rate from the shredders. The existing configuration limits thermal processing area throughput because of shredding rate limitations. In addition, parallel transfer conveyors from each shredder to the thermal processing area should be installed. This provides the redundancy required to insure maximum equipment availability.

An alternate size reduction system based on lower-cost equipment such as flail mill may prove attractive. Without the storage and recovery system in the process line, refuse particule size control becomes less critical, and other candidates for this function become attractive.

Another possibility is the installation of a primary trommel ahead of the size reduction units. The large-diameter trommel used at Recovery I in New Orleans has been demonstrated to increase the efficiency of shredder operation and appears to be particularly attractive as a possible addition to the Landgard® process. This unit removes a large percentage of the glass present in the waste stream before shredding. The effect of this configuration has been to increase material throughput and reduce wear on the shredder units. An accompanying benefit is the reduction in the ash and glass contained in the fuel product. This reduction would lessen the tendency for slag formation in the thermal processing area and reduce the quantity of ash and residue to be handled in the process equipment. Problems have been encountered, however, in removing floating ash from the residue quench tank when magnetics were removed ahead of thermal processing (see kiln experience). If a trommel were employed, a mechanism would need to be developed to assist in removing the floating ash from the residue quench tank. The nominal cost and substantial benefits that could be realized with this piece of equipment make it an attractive component for use in the Landgard® process. This approach would allow material separation before thermal processing and would minimize the number of times material has to be handled during processing.

Alternatively, a trommel could be used in place of the shredders to remove the cans and glass from the process stream and thereby achieve the benefits noted above. Observations of the size characteristics of the Baltimore waste indicate that the larger particles are in the burnable category and could be fed directly to the process kiln.

Although the kiln has been made to operate acceptably, there are several improvements that should enhance process control of this vessel. These changes would involved locating process monitoring and control equipment at the midpoint of the kiln. By installing air inlets at various points along the kiln (by mounting fans on the kiln shell) the reaction occurring in the kiln can be more precisely controlled than is the case when attempting to accomplish this entirely from the discharge end of the vessel. Gas composition and temperature monitoring probes would also need to be mounted along the kiln to utilize effectively the improved control equipment. This equipment is all state-of-the-art in industries using process kilns, and it should prove reliable when adapted to this application.

Preliminary studies performed with the kiln model developed by Systech indicate that the geometry of the processing kiln in Baltimore is not the optimum for effective processing. Further theoretical work is required to refine the optimal kiln proportions for processing municipal solid waste at specific feed rates.

An alternative to the proposed modification of the gas purifier would be to employ a waterwall concept to cool the gas stream rather than to discharge the heat into the atmosphere. A waterwall-type vessel contains water tubes either on or embedded in the internal surface of the vessel walls. Water flows through these tubes and is warmed by the heat evolved from the process. The configuration of this type of vessel is similar to that of a boiler. The heat transferred in this system would be used to preheat the boiler feedwater and would thereby be recovered. The waterwall tubes would be covered with a layer of refractory to protect them from heat damage or slag attack on the inner surface of the vessel. By operating the gas purifier at a high excess air level and by using a waterwall vessel, the process could be operated in a nonslagging mode without the substantial loss of efficiency that would occur in the proposed modifications.

Because the Landgard® system has been determined to be a technically feasible system for the disposal of municipal solid waste, further investigations of this system are warranted. The low reliability of the existing system precludes its economic viability and must be overcome before further system development. The configuration existing at the Baltimore facility is not believed to be optimal, and the development of new process components are recommended. Although the modifications being executed by the City of Baltimore are having a negative effect on process efficiency, the aim of simplifying the process is the key to commercial development. Any further development of the system should be in the direction of simplification and reduction of capital and operating costs. As new components are demonstrated in the application of resource recovery from municipal solid waste, they should be considered in conjunction with the Baltimore processing concept.

μσ 1712b
SW-175c.2

☆U.S. GOVERNMENT PRINTING OFFICE: 1979—281-147/80